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Skill Training Using Adaptive Technology: A Better Way To Hover

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TABLE OF CONTENTS

LIST OF FIGURES	VI
INTRODUCTION	1
ARMY AVIATION TRAINING	1
ADAPTIVE TRAINING	2
PROGRAM OBJECTIVE	3
INSTRUCTIONAL CONCEPT	3
STUDENT PERFORMANCE HISTORY	4
THE INSTRUCTIONAL TECHNOLOGIST EXPERT SYSTEM	5
LITERATURE REVIEW.....	5
CUE HIGHLIGHTING.....	5
MODELING	5
TASK DECOMPOSITION.....	6
PROGRESSIVE DIFFICULTY	6
COGNITIVE TRAINING	6
OBSERVATIONAL LEARNING	7
EVALUATION OF ARTIFICIAL INTELLIGENCE (AI) TOOLS.....	7
ADAPTIVE TECHNIQUES	8
AMBIENT CUES	8
CONTROL FORCE GRADIENTS CHANGES	8
“FLY-TO” DISPLAYS	9
GODS EYE VIEWS.....	9
HIGHLIGHTING OF SALIENT CUES	9
MULTIPLE MODE ERROR SIGNALING	10
PREDICTED POSITION DISPLAYS.....	10
RADIO CHATTER CONTROL	10
THREE DIMENSIONAL SOUND ERROR SIGNALING	10
TIME EXPANSION	11
WIND AND TURBULENCE.....	11
SUMMARY.....	12
REFERENCES	13
ACRONYMS	14

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APPENDIX 1	1
APPENDIX 2	1

LIST OF FIGURES

Figure 1. TH-67 "Creek" helicopter used in Initial Entry Rotary Wing Flight Training.....	2
Figure 2. Block Diagram of an Adaptive Training System.....	3

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Skill Training Using Adaptive Technology: A Better Way To Hover

INTRODUCTION

The goal of this Phase 1 Small Business Innovation Research (SBIR) program was to determine the feasibility of developing and implementing an automated, adaptive hover training controller based on human performance models and novel feedback techniques for Student Pilots (SPs) in Initial Entry Rotary Wing (IERW) training. The target system for the controller is the Intelligent Flight Trainer (IFT), a hover training research device, operated by the U.S. Army Research Institute, Ft. Rucker Field Office, Ft. Rucker, Alabama (ARI). This work was conducted between April and August 2000 by Monterey Technologies, Inc. (MTI) with significant consulting from Dr. Anthony P. Ciavarelli of the U.S. Naval Postgraduate School, Monterey, California and Mr. Charles Asbury of ThoughtWave, LLC, Torrance, California.

Aviation training programs are some of the longest, most costly, and demanding in Army. ARI is continually conducting research to find ways to improve the efficiency and reduce the cost of training SPs to become Army Aviators. The ability to hover a helicopter is one of the fundamental skills required early in the IERW program. At present, IERW is conducted on a training time basis. That is, within a small range of variation, all students receive the same number of hours of training in lock-step fashion. A more efficient training program would be performance based. SPs would advance through the program based on demonstrated individual proficiency. While Instructor Pilots (IPs) have the responsibility to assess performance, it would highly desirable to have automated systems that would adapt the training challenge within a lesson to the current level of the SP's performance and also assess when the SP is capable of advancement to a new lesson or, in some cases, be regressed to a previous lesson.

ARMY AVIATION TRAINING

The primary phase of the US Army IERW flight training syllabus for helicopter pilots requires approximately 10 weeks to complete. During this time each student receives about 60 hours of instruction in the TH-67 Creek helicopter. Subsequent combat skills training requires 8 weeks with 4 additional weeks for Night Vision Goggle (NVG) training, and uses 49 hours in the aircraft. So, a pilot making normal progress will have received at least 28 weeks of training and used about 129 hours of aircraft time even before beginning training in advanced aircraft such as the UH-60 or AH-64 (Wightman, 1999). All of this training is conducted at Fort Rucker, AL in TH-67 Creek helicopters (see Figure 1). The TH-67 is a variant of the Bell Jet Ranger helicopter. Simulators are used only during non-contact (i.e., instrument) training, which follows IERW.

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Figure 1. TH-67 “Creek” helicopter used in Initial Entry Rotary Wing Flight Training.

IERW flight training consists of 59 flight hours flown over 49 flight training days (US Army, 1999). Simulators are not used during IERW training at the present time. One of the first challenges for the SP is to learn to hover the helicopter. Most SPs require 6 to 8 hours to hover competently. By about 10 hours of flight time they should be able to maneuver the aircraft from one position to another in a hover taxi. Most students solo with about 22 hours in the aircraft.

ADAPTIVE TRAINING

Adaptive training is the process of altering the delivery of instruction to match the student's current skill level and cognitive model of the task. As there are individual differences in the rates students learn complex motor skills and the style of instruction that is most effective, adaptive training systems must tailor the training to an individual student.

The ARI IFT is an example of a device employing adaptive training algorithms. The stability of the IFT is varied based on the measured performance of the pilot within a simulated flight session. When the pilot is performing poorly (i.e., position and altitude variability is high while attempting to hover) the aircraft model is made more stable. As the pilot maintains the parameters more closely, the stability of the simulated helicopter is decreased until, at the lowest level of stability, the simulator flies like the actual helicopter. If the pilot's performance deteriorates, then the stability of the simulated aircraft is increased.

The IFT also provides automated verbal feedback to the pilot. For example, if the aircraft is drifting outside of predetermined limits, the voice system will alter the pilot to the drift. If an appropriate correction is not made the voice system will then alert the pilot to the problem and recommend a control input to correct the problem.

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As currently configured, the IFT does not actually use a model of pilot or the student in determining how and when to alter the simulator or offer verbal feedback to the pilot. Changes in stability and verbal feedback are based solely on the variability of the aircraft's position over time.

Adaptive training is expected to be more efficient than in traditional lockstep programs because the student is always performing an appropriately difficult psychomotor task. As the skill of the individual student increases, the task is made more difficult. In turn, as the student's skills improve enough to allow adequate performance at the new difficulty level, the difficulty is again incremented. Should the student's performance decline, then the stability of the simulated helicopter is increased. The student does not spend any time performing tasks at a level already mastered, nor is the student's task so difficult that it interferes with the improvement of the desired skills. In many ways, the adaptive system mimics the performance of an expert instructor.

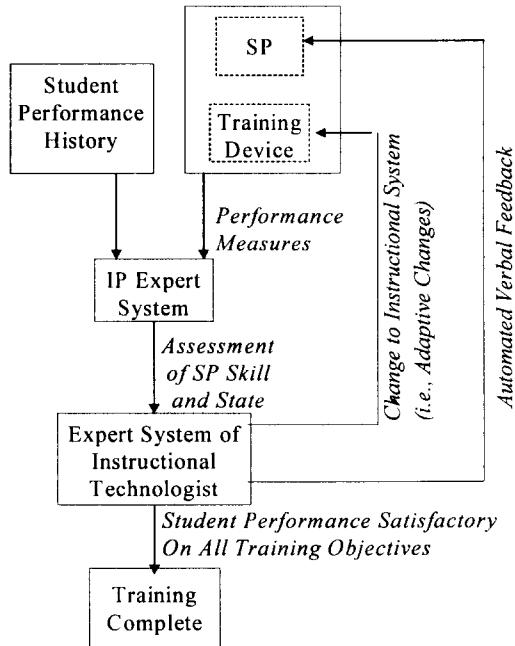
PROGRAM OBJECTIVE

The goal of this program is to determine the feasibility of designing and implementing a successful adaptive training program to instruct SPs the skills and knowledge needed to hover.

INSTRUCTIONAL CONCEPT

Figure 2 is a block diagram showing the key elements of MTI's conception of adaptive training system for a hover trainer.

Figure 2. Block Diagram of an Adaptive Training System.



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In this figure, the “IP Expert System” receives performance measures from the SP flying the training simulator. It also receives input on the previous performance, performance trends, and effects of previous trainer adaptations for this particular student. This expert system uses the historical data and the current performance measures to assess the state of the student. If the student has not mastered the task or, more accurately, is not performing at the appropriate level for that point in the training schedule, then the system diagnoses the student’s difficulty. If the student demonstrates mastery of the task, then the system moves on to the next training objective and does not waste time on the already mastered task.

STUDENT PERFORMANCE HISTORY

The student performance history information is critical to this process for several reasons. First, and most obviously, the expectations and performance criteria for a SP on the first flight are different than for a SP who has already had several hours of practice. Similarly, the type of adaptation and feedback that is appropriate will depend on the state of the SP. When just beginning it is expected that the SP will be attempting to understand the plant dynamics. That is, the relationships and interactions between the controls and changes in attitude and position of the helicopter. The SP will be under high cognitive workload to identify these relationships and it will be expected that the types of adaptation and feedback will be focused on making the plant dynamics apparent. Visual cue augmentation and slower than real time simulation, along with alteration of the helicopter’s stability, are candidate methods of adaptation at this phase of learning. Later, after some practice which allows the SP to understand how the control work and interact, the focus of training will normally shift to developing the fine psychomotor skills needed to control the aircraft in real time without “thrashing” or “under-controlling” the controls. At this point in the skill acquisition process altering the proprioceptive feedback by either damping the control motion velocity to an appropriate level (or removing damping if the SP tends to feed in controls too slowly), or perhaps limiting the control authority, might be more effective ways to adapt the trainer.

A second, but perhaps less obvious, use of the historical data is to predict future performance of the SP. The adaptive system should have the capability to categorize the student. Where students who fit the same pattern have previously encountered difficulties at later stages of training, the trainer should alter the training in an anticipatory fashion. By adapting the trainer early, it may be possible for the current student to avoid the problems encountered by students who have passed before. As an example, consider the following hypothetical pattern of SP performance. At an early point in training, students tend to fall into two categories; those who over-control the fore-aft cyclic and those who tend to under-control it. Assume that students who over-control the fore-aft cyclic later tend focus on this so much that they fail to use sufficient lateral cyclic. In this example, the IP Expert System would diagnose the current problem and predict the development of the future problem. This would allow the IT system to modify the trainer to discourage thrashing the stick in the fore-aft direction without letting active lateral stick control become extinguished.

When a task is considered “mastered” that it does not necessarily mean that the SP is performing at the level of an experienced, expert helicopter pilot. In this context it means that the student

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has reached the level of proficiency required to begin learning new training objectives. This is no different than the current practice in IERW training. Once a student can perform a maneuver "good enough" an IP moves on to the next challenge.

THE INSTRUCTIONAL TECHNOLOGIST EXPERT SYSTEM

The Instructional Technologist (IT) Expert System receives the diagnosis from the IP system as input. The IT system using a prescriptive process to determine the type and magnitude of the change in the simulator, if any, that is appropriate. Once the change is determined, this system causes the change to be implemented in the trainer. In those instances where the training prescription is to provide voice feedback to the student, the IT system causes the message to be broadcast to the SP.

When the objectives for that session have been reached then training is considered complete for that session. Other criteria may also be used to end a session. For example, if the student is not progressing and becoming frustrated to the point that training is impaired in that session, then the system would terminate the session and store information that would allow it to resume training where it left off. This would provide the student an opportunity to "settle down" and think through the problem.

LITERATURE REVIEW

A review of the literature review relevant to learning and adaptive training was conducted as a part of this effort. This review showed that the instructional prescriptions for complex skill training, unlike prescriptions for cognitive training, are not well developed or validated operationally. Therefore, at this time one can only extrapolate from the results of laboratory studies.

The literature review is contained in its entirety in Appendix 1. Key points from the literature review are synopsized below.

CUE HIGHLIGHTING

Gibson (1966) and others (Merrill, 1972) have suggested that skill training can be facilitated by highlighting important cues for the student. In other words, the instructional system should be designed so that the student's attention is focused on the visual, vestibular, auditory, and proprioceptive cues that indicate changes in helicopter state. As an example, one might highlight the tip path plane in the visual scene so that the SP begins to attend to it, rather than waiting for the SP to discover the relationship between changes in the tip path and future changes in the helicopter's position or velocity.

MODELING

Gibson also suggests that demonstrating the relationship between the cues and the actions that the student should make in response to changes in those cues will improve training. Modeling the correct control motions is certainly important in terms of giving the SPs an example of the performance that should be ultimately reached. However, as it is unlikely that SPs thrashing the controls don't realize that they are over controlling the aircraft. It is likely that modeling at a more fundamental level would benefit a SP. In particular, what may be required in addition to

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modeling the ultimate performance is to use the modeling effort to provide the student an understanding of the “plant dynamics.” That is, the instructional system should use modeling to augment the cognitive training on the effects of each control and the interactive effects of the controls on the aircraft.

TASK DECOMPOSITION

One training strategy is to decompose the task into segments and allow the student to practice each of the segments individually before performing the task in its entirety. It appears from the literature that this approach can be successful under certain conditions. Wightman and Lintern (1985) found that segmentation, particularly when the task is trained using backward chaining, can be effective. They recommend:

- Isolating consistent task elements for focused practice
- Providing repeated practice with feedback
- Practicing critical tasks separately to avoid information overload
- Training to an acceptable level of accuracy
- Incorporating extrinsic motivational conditions

Backward chaining has been demonstrated to be an effective training approach in teaching the skills required for air-to-ground bombing (Bailey, Hughes, and Jones, 1980) and in teaching carrier landing (Wightman, 1983).

PROGRESSIVE DIFFICULTY

There results reported in the literature on the effectiveness of changing the difficulty of a task suggest that this is not a particularly effective approach to training. Wightman and Sistrunk (1987) found that the progressive difficulty approach was inferior in terms of training effectiveness when compared to part task segmentation. Mané investigated the effect of altering the speed of a video game on skill acquisition. In this study the game was slowed down for beginners and increased the speed as skills increased. In other conditions, the students either practiced the game at normal speed or received part task training. The learning rates of students in the progressive difficulty and normal speed conditions were inferior to that of students who received part task training.

While the available data does not rule out the possibility that selecting other rates of changing difficulty will be effective, it appears that this approach is not highly likely to be particularly successful in the hover training application.

COGNITIVE TRAINING

Smith (1984) examined the effects of providing cognitive training before or during skill acquisition training. There were four groups in this study. One group received cognitive training prior to the start of skill acquisition training. A second group received the same pre-skill acquisition training as the first group coupled with sporadic cognitive training during the skill acquisition training. A third group received no cognitive training prior to beginning skill acquisition training, but received sporadic cognitive training concurrently with skill acquisition training. A control group received no cognitive training either before or during skill acquisition training. Interestingly, Smith also found that cognitive training had a beneficial effect only when

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presented before beginning kill acquisition training; providing cognitive training sporadically during skill acquisition had an adverse effect. The conclusion reached is that the timing of cognitive training relative to skill acquisition training is critical.

The implication of this finding is that IERW should be structured so that the ground school sessions covering fundamentals should precede the start of flight training. Further, these results suggest that cognitive training for specific maneuver should always precede the flights in which the maneuver is practiced.

OBSERVATIONAL LEARNING

The literature generally shows that observational learning is more effective for cognitive tasks than for tasks that are predominately psychomotor tasks (Goettl and Gomez, 1995). This result is consistent with the notion that improvements in psychomotor performance is marked by increased automatization of the task. Simply, observation does not provide the student with adequate opportunities to allow the skill to become “ingrained”.

EVALUATION OF ARTIFICIAL INTELLIGENCE (AI) TOOLS

An intelligent, adaptive training system will require software be created that can (1) assess the student and identify training needs (i.e., a model of an expert IP) and (2) can translate the identified training needs into changes in the training delivery system (i.e., a model of an instructional technology expert). It would be more efficient and present less technical risk to the program to create these models using COTS tools developed to support AI applications than to write all the software in-house.

A review of AI approached and tools was conducted as a part of this program. This review is contained in Appendix 2. Key points from this review are presented below.

Initial efforts focused on identifying the approach or approaches that would be appropriate for creating these systems. Technologies considered included:

- Conceptual Graph Analysis
- Case Based Reasoning
- Modeling and Simulation
- Neural Networks and Genetic Algorithms

Case Based Reasoning (CBR) is the approach recommended for developing the Instructor Pilot and Instructional Technologist models. The benefits of CBR that make this approach the most attractive of those examined are:

- The ability to quickly find solutions to complex problems
- Discovering decision knowledge using inductive reasoning
- Transferring experience from skilled specialists to novices
- Pooling individual experiences into a shared pool of domain knowledge
- Demonstrating expertise in domains that are poorly understood, including domains where the theoretical underpinnings of successful solutions are undeveloped.

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- Penetrability – it is relatively easy to determine how the system reached a decision
- Maintainability – rules that do not support the objective can be modified or deleted, or new rules added easily

Once an approach had been identified, a number of COTS tools were identified and examined. The recommendation coming from this review is that the adaptive training system be built using the *Easy Reasoner*, *CBRete++*, and *CPR* packages, with additional software to support the packages and integrate the system being written in *C++*.

ADAPTIVE TECHNIQUES

After the expert IP has assessed the student's performance and identified a strength or weakness, the training device must be altered. The type of modification made must be appropriate to the particular aspect of performance to be modified through training. Alterations along a single dimension, such as in terms of aircraft stability as is now done in the IFT, will be useful in some instances, but are likely to be inadequate to address the entire range of instructional issues that are encountered.

The role of the instructional expert model is to identify the manner in which the simulator should be altered to best suit the student. Below are brief descriptions of additional characteristics of the training system that could be altered to meet the needs of the students. This list is intended to show the range of simulator characteristics that can be modified. It is not an exhaustive list. The set of features that could be adapted is limited only by the creativity of the people developing the system and the capabilities of the specific training simulator.

A major part of the process of developing an adaptive system will be measuring the effectiveness of the manipulations made to the training system.

AMBIENT CUES

If the student is having trouble judging motion of the aircraft in one or more specific axes, then overlay a grid pattern on the terrain and, if the motion is vertical, on vertical panels around the helicopter. This will provide motion cues that are more robust than those available in the relatively sparse visual scenes.

In extreme cases, or cases where it is desirable to increase the response amplitude of the pilot, the motion of the ambient checkerboards can be amplified. For example, if the pilot has trouble detecting changes in heading, move the checker board through a larger angle than that through which the aircraft moves.

CONTROL FORCE GRADIENTS CHANGES

In this approach, the pilot is discouraged from making control movements of excessive amplitude or excessive velocity through the use of force gradients. For example, if the SP moves the control too quickly, control damping is added so that whenever the velocity exceeds the desired maximum velocity the amount of force required is noticeably above the force required to

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move the control the same amplitude at a rate at or below the acceptable level. In the case of excessively large amplitude motions, the force would increase as the control reaches and exceeds the desired maximum.

If, on the other hand, the control motions were not of sufficient amplitude or if the velocity of the input was too slow, then the force could be reduced below the nominal level. This, I predict, would have less of an effect than in the situations where the force is increased when the limit is reached.

This could be applied to any control function where the operator has a desired range of control motions and/or amplitudes. Driving automobiles is one example. Student drivers tend to be overly active with the wheel, as if they are modeling the driving style from an old, bad movie.

“FLY-TO” DISPLAYS

Instead of a predictor display, the pilot could be given a “fly to” display. This would provide continuous, instantaneous feedback to the pilot regarding the direction and magnitude of the control input error. The pilot would be able to use this display to develop the “muscle memory” relating the aircraft state and the control input. The pilot would need to be weaned from this display in order to internalize the skill. Otherwise, the pilot would be a cripple and rely on the cue to control the aircraft.

GODS EYE VIEWS

Use a God’s eye view. In this approach, the student pilot (SP) views a helicopter from a position to the behind the helicopter. The position might also be behind and above the helicopter. This will allow the SP to learn the control laws/plant dynamics. For example, the SP can see the effect of adding lateral cyclic to stop or start lateral drift. They will also be able to easily detect aircraft yaw motion as they pull in collective.

The commercial potential includes teaching people to back trailers. One could imagine using this in initial truck driver training. It could also be used by rental agencies (e.g., U-Haul) to let renters practice backing a trailer.

Another application is teaching student drivers to parallel park an automobile. In this case, you would probably want to start with the fenders being transparent so that the student can see the position of the tires. Later, the fenders should be opaque so that the student has to learn to rely on the cues from just the position of the steering wheel without being able to visually ascertain the position of the tires.

HIGHLIGHTING OF SALIENT CUES

There are cues that the student needs to attend to in the aircraft. A student enters the program not knowing what cues to attend to. These cues may be available in any modality including:

- Sound
- Visual
- Vestibular

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Since the student doesn't know what to attend to and what to ignore (what is critical vs. what is junk) he or she may be left to "discover" the cues on his own. This is inefficient at best, and may result in the student failing to recognize and exploit appropriate information sources. (For example, students can't be expected to realize the importance of the position of the rotor disc. As the disk tips forwards, the aircraft will pitch and then move forwards.). The simulator should help the pilot identify and attend to the cues needed to perform maneuvers.

MULTIPLE MODE ERROR SIGNALING

Provide the pilot cues in a modality that is not normally used in recognizing the error. For example, if the pilot is working on aircraft roll control, change the pitch of a sound so that when the left wing is low the pitch of the sound goes up, and when the right wing is low the pitch of the sound goes down. This could be used to cue the pilot on any axis. The pilot would be "weaned" from this cue once performance met some criteria.

PREDICTED POSITION DISPLAYS

If the pilot is having trouble relating the magnitude of control inputs to the situation, provide a predictor display. The predictor display would show the position of the aircraft in TBD seconds given the current control input.

You would want to experiment with different orders of the prediction equation. For example, you might want to use a linear extrapolation given the current velocity of the aircraft (for a translational error), or use a higher order equation that takes the rate and acceleration into account to come up with a predicted aircraft position. See also the idea of "fly to" displays.

RADIO CHATTER CONTROL

Flying is not done in a quiet environment. There are sounds that students must learn to attend to, and those that they must ignore. At the very beginnings of flight training, students can't (and probably shouldn't) be hearing chatter on the radio. Instead, the system should eliminate the radio chatter during initial flights. Only when the student has began to master the helicopter should potential distractions be added into the simulation.

As the student progresses, he or she must learn to use the radios. Use of the radios includes learning to communicate with the tower and possibly other aircraft. Use of the radios also incorporates learning to monitor the radio for relevant messages while ignoring those that are irrelevant. If the pilot fails in these tasks, he or she will be either inundated with communications to the point of being overloaded or not being aware of messages that are addressed to that aircraft. Certainly, adequate use of the radios (listening, responding, and ignoring) is a skill that must be developed by the time the student is ready to solo.

THREE DIMENSIONAL SOUND ERROR SIGNALING

Use 3-D sound cueing to help the pilot identify the direction of the ideal position from his current position. You could, in principle, make a sound appear to come from in front of or behind the pilot, or to the left or right of the pilot, or from above or below the pilot. This sound could be configured so the pilot flies the aircraft towards the sound. For example, if the aircraft

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is above and to the left of the ideal hover position, the sound would be perceived to be coming from a location below and to the right of the pilot.

The gain on the movement of the sound could be varied. As the pilot becomes more proficient, the size of the error that triggers the cue could be made smaller. That is, at first the amount of error in aircraft that causes the cue to increase is large (e.g., 12 ft). As the pilot becomes more proficient, the distance that the aircraft moves before the position of the sound is changed decreases (e.g., is reduced to 3 ft). Not only does the cue adapt during training, but the pilot needs to be weaned from the cue as the skill level increases.

TIME EXPANSION

The entire simulation could be slowed down. This would allow the pilot to explore the plant dynamics by putting in a control input and observing the effect on the aircraft's attitude and position. By slowing the entire simulation down, you provide the pilot the opportunity to observe the sequence of effects. For example, as lateral stick is put in the aircraft first banks and then begins to translate. As the bank increases, the pilot needs to add power to maintain altitude.

As another example, as the pilot puts in rudder the aircraft changes altitude unless the appropriate collective changes are made. This approach is likely to be most useful in teaching the pilot the plant dynamics. It is not likely to be appropriate when the pilot is trying to master the psychomotor task itself. It would not be appropriate to delay the effect of a control input if the rest of the simulation were running in real time. This would increase the likelihood of simulator sickness and of introducing pilot induced oscillation (PIO).

WIND AND TURBULENCE

Winds and turbulence can be added to the simulation to increase the difficulty of hovering. Essentially, these winds disturb the aircraft and force the pilot to make control inputs to maintain a stable hover. Early in training, the pilot has more than enough to do in calm conditions and can't cope with the disturbances. However, as skill increases, the pilot needs to recognize changes in aircraft position not caused by control inputs and learn to make the control inputs to counteract the disturbance. In an ideal world, the pilot would be trained enough in the simulator that the winds in the real world during flight, which is almost never dead calm. (I assume that they have some weather standards/minimums for initial flights and don't go out with students if it is blowing 40 with gusts to 60!)

The application would be to add weather conditions as the pilot demonstrates that he or she is able to maintain position within criterion.

One of the important things the pilot needs to learn about winds is that the aircraft can translate without a change in attitude. A pure cross wind, for example, will cause the aircraft to translate sideways. Getting the aircraft to translate requires a change in attitude.

Constant winds require the pilot to maintain a non-standard attitude. Simply, the aircraft must be banked an appropriate amount into the wind to maintain position. As with any change in bank angle coordination with the collective and rudder is necessary.

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Gusty winds are similar to constant winds in that they move the aircraft without changing the aircraft's attitude. The difference is that with the gusts the pilot must constantly make corrections, and can't ever hope to maintain position by setting the controls in one position.

SUMMARY

This work suggests that it is feasible to incorporate adaptive training into a hover trainer for use in IERW. While we expect that an adaptive training approach will ultimately lead to improved training efficiency, the literature provides little guidance on how to adapt a psychomotor skills trainer, under what conditions changes to the trainer should be made, and the expected magnitude of improvement in training efficiency expected from specific adaptive strategies. Therefore, in our opinion, it is impossible to make a reasonable quantitative estimation of the effect implementing an adaptive training system will have on *ab initio* hover training at this time.

A variety of approaches to developing models of an Instructor Pilot (IP) and Instructional technologist (IT) were considered. based on this review a Case Based Reasoning approach is recommended. COTS tools develop and implement the IP and IT models were reviewed. The recommended set of tools consists of *Easy Reasoner*, *CBRete++*, and *CPR*. Additional software to support the packages and integrate the system should be written in C++.

The area that present the biggest challenge to an adaptive hover training system are determining the prescription for each possible student state and assessing the effectiveness of that prescription. The literature provides very little guidance regarding the selection of adaptive features and when they should be employed. Consequently, a major effort to determine the utility of various adaptive techniques is required. A set of candidate adaptive techniques which may be prescribed for particular student states and skill levels are described.

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ACRONYMS

ARI	Army Research Institute
IEWR	Initial Entry Rotary Wing Training
IFT	Intelligent Flight Trainer
IP	Instructor Pilot
IT	Instructional Technology, Instructional Technologist
MTI	Monterey Technologies, Inc.
NVG	Night Vision Goggle
PIO	Pilot Induced Oscillation
SBIR	Small Business Innovation Research Program
SP	Student Pilot

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APPENDIX 1

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**SKILL TRAINING USING ADAPTIVE TECHNOLOGY:
A BETTER WAY TO HOVER**

SBIR 0SD99-04

**Literature Survey and Analysis
(Interim Report)**

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**July 17, 2000
REVISION OF BIBLIOGRAPHY**

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PREFACE

The following report was prepared, as planned, with a focus on laying a foundation for construction of an Intelligent Flight Trainer (IFT) for teaching rotary-wing hovering tasks. A major re-direction of the project was discussed during a project coordination held on 24 May 2000 at Monterey Technologies, Inc., Monterey CA. At that meeting the project team was informed that there would be a major change in project direction. This report was completed in draft form prior to this meeting, and therefore the content still reflects the study's original intent to develop an intelligent hover trainer. The report is incomplete in sections related to mission definition, learning objectives, and definition of baseline trainer design comparisons. It is understood that the instructional design methods and related training system development material presented herein still represent a useful point of departure, with substantial application to whatever new learning domain is finally specified in the project planning redirection instructions.

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INTRODUCTION

PURPOSE

A review and discussion of the complex skills training literature was conducted. The purpose of this literature review was to help establish a foundation for the development of An Intelligent Flight Simulator for hover training. The work was performed under contract to Monterey Technologies, Inc., Monterey California and was in support of an SBIR contract (OSD99-04) with the US Army Research Institute Rotary Wing Aviation Research Unit, Fort Rucker Alabama. The scope of this literature review was limited to a narrow band of skill acquisition and simulation literature that could be accessed in the short time period available for the SBIR study. The results and implications for the design of an adaptive training system deduced from this body of work are described below. Synopses of selected references reviewed during this effort are contained in Attachment A. It is recommended that a more extensive literature be conducted if the study progresses into a Phase II effort.

BACKGROUND

The US Army has an interest in exploring emerging technologies, including artificial intelligence, and their application to advanced flight simulation training. Methods to enhance simulation training include the use of student and instructor expert systems that learn and adapt instruction to the learning needs of a pilot undertaking flight instruction. The basic concept is that of an "adaptive trainer", which refers to a training system that uses student performance during training as a means to adjust or adapt the level, or content of instruction to improve learning efficiency or effectiveness.

A previous study performed by Mulgund, Asdigha, and Zacharias (1995) served as a point of departure in defining several baseline architectures for an Intelligent Flight Trainer (IFT) founded on principles of adaptive training. This particular adaptive trainer provided adaptive control of hover task difficulty, and a synthesized voice feedback system that provided flight instructional guidance in an attempt to enhance training.

Information gathered from this literature review, including studies of human skill acquisition, flight simulator training effectiveness experiments, and further discussions regarding human learning, the use of performance feedback, and other instructional strategies suggest that the issues surrounding the use of adaptive training are quite complex. Some of the findings in the literature are inconsistent on key issues concerning the nature and extent of feedback that should be provided to the learner during training, and the permanent learning benefit of some instructional strategies. This report summarizes areas of agreement and disagreement in the literature and discusses a number of potentially useful instructional methods that have been successful for teaching both cognitive and perceptual-motor components of complex motor skills. Information provided here could be a useful point of departure for comparing various

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approaches to the use of expert systems in simulation training, and for defining baseline training system architecture that incorporates an adaptive training approach.

ANALYSIS OF SELECTED LITERATURE

COMPLEX SKILL ACQUISITION

Laboratory studies of complex skills have established a useful, but limited, framework for understanding how best to organize training and teach flying skills. A good point of departure for discussing various teaching strategies for skill training is provided by Schneider (1985), as outlined below:

1. High-performance skills are characterized by three things:
 - The length of time to become competent and proficient at the task.
 - A typically high failure and non-completion rate for training.
 - There is a considerable performance difference between a novice and an expert.
2. Novices appear “overtaxed” and are easily distracted during performance, whereas the expert appears to perform smoothly and without effort, and is not easily distracted.
3. As one moves progressively, from novice to expert, the performance changes (in terms of competency exhibited and very likely in terms of the information processing and control tasks performed).
4. The expert makes decisions much more rapidly based upon experience, and without much “thinking” or deliberation (p. 286).

During the course of learning most complex skills, learners appear to progress through distinct stages. There is considerable agreement in the literature about the number of stages (three) and the events and characteristics that define each stage (Lane, 1987; 1986).

Fitts (1962) was one of the first skill researchers to postulate these phases of learning that he called (1) Cognitive, (2) Fixation, and (3) Autonomous. One of the most important things that Fitts observed was the early influence of cognitive processes on the acquisition of perceptual-motor skills.

During this cognitive phase, learners attempt to “intellectualize” the requirements for learning the skill, and seek to establish some knowledge about the nature of the task to be performed (Fitts, 1962).

During the “fixation phase”, the learner attempts to correct errors and begins to focus, or fixate on the most appropriate response patterns for accurate task performance. The final or autonomous learning stage is characterized by a considerable improvement in timing and coordination, and faster and more accurate performance. There is increased “automaticity”, resistance to distractions, and a shift from dependence upon external cues to internal (proprioceptive) stimuli. During later refinement of the learning stage model, Fitts and Posner

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(1967) changed the term *fixation* to the term *associative*. The term associative is one that is easily incorporated into contemporary cognitive theories of learning.

Stage learning models were also proposed in the cognitive domain. Anderson (1982) formulated a three stage learning model that distinguished between *procedural knowledge* (represented by production rules), and *declarative knowledge* (represented by propositional networks).

The stages of learning proposed by Anderson were reviewed and nicely summarized by Lane (1986, p 132.), as follows:

- a. **Declarative.** The learner receives facts, information, background knowledge, and general instruction about a subject matter or skill. Mental elaboration and rehearsal at this stage helps to keep information presented in working memory.
- b. **Knowledge Compilation.** Practice causes basic knowledge about a skill to convert gradually from declarative form into appropriate new procedures that can be applied directly to the processing of inputs without constant voluntary attention. This stage is comparable to Fitt's associative stage and represents formation of a set of production rules linking input to output.
- c. **Procedural.** After declarative knowledge is compiled into a production system, practice refines and strengthens appropriate procedures. Ultimately responses reflect improved discrimination and generalization and become automatized.

The phased progression of learning into distinct stages by Fitts (perceptual-motor learning) and further developed by Anderson (cognitive learning), strongly implies that the typical learner transitions from a state of *knowledge about* a subject or skill, to a state of *rule application*. This phased development model has important implications for the delivery and assessment of instruction for both cognitive and perceptual-motor learning.

Fitts and Posner (1967), who made the following suggestions recognized the need for different instructional strategies, at initial and later stages of perceptual-motor learning:

1. During early learning phases, "call the learner's attention to important perceptual cues and response characteristics, and give diagnostic knowledge of results (p.11)".
2. Demonstrations of correct performance of the task are, "most effective during early learning phases (p.11)".

Most complex skill researchers agree that instructional strategies must adjust to the learners state of learning, or learning phase. Schneider (1984) stresses the importance of different practice strategies for controlled processing and for automatic processing modes of skilled performance. When a learner is in early learning stages, and exhibiting primarily controlled processing, the instructional strategy would be to provide practice on wide variety of conditions. When learners have reached the automatic processing skilled performance level, then they should be presented with consistent task elements repeated over many practice trials (Fisk, Scerbo, and Schneider, 1983).

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Instructional psychologists have incorporated some of the findings from the complex skill studies in their theories of instruction design. Gagne' and Briggs (1979), for example derive their instructional presentation methods for the cognitive domain based on some of the aforementioned human learning and information processing principles.

In answer to the question, "How is the student coaxed along during instruction", Gagne' and Briggs outline some of the critical events of instruction as follows:

1. Gaining attention
2. Informing the learner of the objective
3. Stimulating recall of prerequisite instruction
4. Presenting stimulus material
5. Providing learning guidance
6. Eliciting the performance
7. Providing feedback about performance correctness
8. Assessing the performance, and
9. Enhancing learning and transfer (p. 157)

Merrill (1980, 1983) believed that the approach taken by Gagne' and Briggs was in the right direction, but suffered from a lack of specificity. He proposed a *Component Display Theory (CDT)* of instruction that represented a systematic and detailed procedural framework for teaching cognitive skills. Merrill's instructional strategies included procedures for defining and classifying cognitive tasks, and then systematically organizing instruction around the classification of task-based learning objectives. The instructional design theories proposed by Gagne', Briggs, and Merrill are sometimes referred to as "prescriptive" instructional theories because they take defined learning outcomes (typically specified as learning outcome objectives) and recommend a particular instructional presentation and assessment method.

Prescriptive Instructional Methods for the Cognitive Domain

A prescriptive approach to instruction represents an attempt to determine the optimum method for teaching and assessing specific learning outcomes. Glaser and Resnick (1972) outline some of the key characteristics of a prescriptive approach as follows:

1. Description of the state of learning to be achieved.
2. Description of the initial state of the learner
3. Actions that can be taken to transform the initial state into the desired state.
4. Assessment of the transformation of the state to determine learning results of each (instructional) action taken.
5. Evaluation of the attainment of the terminal state desired (p. 208).

Prescriptive methods of instruction grew out of dissatisfaction with attempts to directly apply general principles of learning that were developed in the psychological laboratory. Gagne' (1962), for example, found few of the commonly accepted laboratory learning principles, such as response reinforcement and distribution of practice, to be useful in practical learning situations.

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Gagne' formulated one of the first prescriptive theories of instruction, base upon his study of military training in late 50's and 60's.

His recommendation about organizing instruction, outlined below, became the hallmark of prescriptive theory:

1. Analyze component tasks.
2. Specify method for teaching each component task (of a particular skill).
3. Specify instructional strategy, presentation sequence and select media most appropriate for each phase of training. (Adapted from Gagne', 1962, p. 86).

Categories of Learning

An organizing principle of prescriptive theories of instruction is the classification of different learning outcomes. Robert Gagne' (1965; 1985) was one of the first instructional psychologists to propose that different learning outcomes require different learning methods or strategies. Table 1 shows his later description of various learning outcomes proposed by Gagne' (Wagner and Gagne', 1988). The examples given for each learning outcome listed were edited for purposes of clarity to this analysis and report.

Table 2 shows some of the recommended learning prescriptions, or teaching guidelines, for selected learning outcomes, based on the theory of instruction developed by Gagne', as discussed in Wagner and Gagne' (1988). The guidelines provided in the Gagne' model has received some criticism for being far too general to be useful in most practical learning situations. Merrill (1983; 1988) further developed ideas originated by Gagne' to formulate a more detailed procedural framework for instruction design, referred to as Component Display Theory or CDT.

TABLE 1: Categories of Human Learning

(Wagner and Gagne', 1988 p. 37)

<u>Learning Outcome</u>	<u>Example of Performance</u>
Intellectual Skill	Use symbols and language to:
Concrete Concept	Sort squares and triangles
Defined Concept	Classify buildings given definitions
Rule	Apply process to reduce fractions
Higher-order Rule	Create math formula derivation
Cognitive Strategy	Create a way to learn a new skill
Verbal Information	State historical facts
Motor Skill	Steer an automobile or an aircraft
Attitude	Choose a favorite person or movie

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Table 2: Examples of Prescriptive Instructional Guidelines for Cognitive Domain
(Adapted from Reigeluth, 1983, p. 94)

<u>Strategy</u>	<u>Intellectual Skill</u>	<u>Factual Information</u>	<u>Motor Skill</u>
1. Gain Attention	(Draw attention by highlighting or changing sensory mode)		
2. Tell Objectives	Show learner performance	Show subject outline or organizer	Present key skill components
3. Stimulate Recall	Provide review or summary of core ideas	Show Subject outline or organizer	Demonstrate performance
4. Present Instruction	Show examples and how to do	State facts, concepts, etc.	Provide simulated practice
5. Provide Guidance	Verbal prompt and aids	Link subject to related material	Provide feedback or guidance
6. Elicit Performance	Ask for solution	Ask for recall of information	Ask learner to perform
7. Provide Feedback	Show correct solution	Confirm right answer(s)	Provide corrective feedback
8. Assess Performance	Learner shows how to do	Learner takes written test	Learner performs task
9. Enhance Transfer	Give variety of practice problems	Provide links to related materials	Give more practice on task

Merrill and his associates (Merrill 1983; Merrill, Reigeluth, and Faust, 1979) developed a prescriptive instructional theory using Gagne' as a point of departure. The so-called component-display theory proposed by M. David Merrill focused primarily on methods designed to ensure high quality instruction for cognitive skills. Merrill believed that the work by Gagne' and other early instructional theorists did much to help systematize instructional methods but left too much open to interpretation by instructional designers.

Component Display Theory (CDT) methods address specific micro strategies for optimizing instruction in the cognitive domain. The principal behind CDT is to arrange instruction in accordance with specific prescriptions for each of several categories of learning outcomes. Cognitive learning outcomes, for example, are classified in two dimensions: (1) the type of subject matter (facts, concepts, principles, and procedures); and (2) the desired performance level on the learning task (remember, use, find). A more detailed background description of CDT, as well as instruction design guidelines and examples is presented in Ciavarelli (1988), and Merrill, Reigeluth, and Faust (1979). *Facts* are arbitrary ideas or events; *procedures* are sequential steps required to perform a specific operation; *principles* are cause and effect relationships; and *concepts* represent classification of things according to common attributes. The *remember*, *use*, and *find* categories respectively memorization, skill application, and cognitive strategy performance levels.

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Table 3 shows the two-dimensional (task X performance level) classification matrix commonly used in CDT.

TABLE 3
Classification of Learning Outcomes for the Cognitive Domain

	FACTS	CONCEPTS	PRINCIPLES	PROCEDURES
REMEMBER (Recall or Recognize)				
USE (Apply)				
FIND (Discover)				

The teaching method used in CDT typically incorporates both primary and secondary instructional presentation strategies as discussed below.

Primary Presentations

Merrill's CDT suggests that instruction be organized around a series of presentations, or displays. Primary presentations are represented by information presented to the learner in terms of "telling" or "questioning" (Tell or Question), as depicted in Table 4. The instructor has a choice of presenting "generalities" of the subject matter or presenting specific examples or instances.

TABLE 4.
organization of Instruction Around Presentation

	TELL	QUESTION
GENERALITY		
EXAMPLE		

If we were attempting to teach a student the differences between a fighter aircraft and an attack bomber, for example, we would define the key attributes that distinguish the two, then show some examples of each. So we can define attributes (Tell/Generality), or we can present examples (This is example of a fighter jet; This is example of an attack jet). The same material can be presented using a question method. We can ask the student to define the attributes, or select correct attribute definition, or we can show an example (picture of either aircraft) and ask the student to correctly identify the example shown.

Secondary Presentations

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Secondary presentations are strategies inserted into the learning situation that help the learner to assimilate the subject matter. Some of the more common “secondary” instructional presentations listed below.

- Advance Organizers (organization charts, subject matter maps, models, graphs, pictures that illustrate key points and structure of learning material)
- Isolation and Highlighting (coloring, pointing to, or otherwise identifying key points or salient ideas or cues)
- Semantic Labels (pointing out meaningful connections and relationships in the knowledge structure)
- Verbal Mnemonics (rhymes, limericks, slogans, and other memory enhancing methods)

Assessment (Written or Oral Exams)

Various forms of testing are used to assess the competency or achievement level of the learner, including written tests and performance demonstrations. The test or performance demonstration is developed to assess a particular performance level specified in the learning objective, such as:

- Memory Level (remember)
- Application Level (use)
- Problem Solving (find)

In general, CDT instructional presentations follow the format summarized below:

1. A “rule” statement related to the instructional content is presented, such as a brief factual statement, definition of a concept or concept class, description of a principle, or listing of steps in a procedure.
2. Following the rule statement (s) related to the core content, some examples of application are presented. For example, in a procedure objective, the correct steps in the procedure would be stated together with the information about an operational conditions, cues, and expected system responses to control.
3. After presentation of one or more examples, instances or demonstrations, the learner would be given a opportunity to recall the correct procedure, concept definition, or key principles taught in the lesson.
4. Following the recall session, the learner would be given a opportunity to practice (apply or use) the procedure, practice classifying concept classes, or solve problems using specified principles, before being tested on content and application. The practice exercises should provide a sufficient range of experience to meet expected competencies defined in the learning objectives. During practice sessions the learner is often given diagnostic, corrective feedback and other guidance to facilitate learning. The guidance is eventually reduced or withdrawn as the learner progresses and prepares for competency testing.
5. The student is given a competency test (without any instructional aids) to measure learning progress, and to determine the need for additional instruction. The test may be in written or oral form, and would be conducted in the reference to the performance level specified in the learning objectives.

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By way of summary, a typical application of CDT calls for analysis of learning tasks, preparation of specific learning objectives and classifying them as to type task and performance level, and then arranging learning in a way that optimizes instruction for a particular task classification.

For example, in developing a concept lesson using CDT, the instruction designer would arrange instruction as follows:

Objective: Sort all aircraft examples provided into fighter jet, patrol, transport, attack helicopter, troop transport helicopter.

Performance: Use concept (sort by defined attributes)

Instructional Sequence:

1. Present Tutorial that defines the concept classes and their attributes.
2. Present examples with concept labels (pictures with identifiers)
3. Item 1 and 2 may be completed simultaneously.
4. Provide learner opportunity to recall concept class attributes and practice sorting into correct classes with immediate corrective feedback of results.
5. Test student at completion of practice trials at appropriate level of performance defined in the learning objective.

In addition to arranging the “primary” instructional presentations as described above, CDT often uses “secondary” presentations to facilitate learning. Secondary presentation methods include prompting and corrective feedback, highlighting key points and critical information, and providing knowledge organizational frameworks, such as flow charts, block diagrams, illustrative animations and simulations. Merrill (1983) believed that such “secondary” instructional presentations, or “displays”, help to elaborate the primary instruction and thereby facilitate the learning process.

CDT attempts to establish instructional quality providing some guidelines that can be used during training development or for assessing the quality of established instruction.

The instructional quality guidelines include ground rules for checking the adequacy of instructional objectives (correct format and content), for checking the consistency between the learning objective and instructional delivery strategy, and between learning objective and associated assessment method (Merrill, 1983).

Finally, CDT accepts that individual learning differences are inevitable and handles differences in ability and learning style by allowing the learner to control the learning process (selection of instructional presentations, the pace of instruction, and the extent of practice sessions to be completed before competency testing).

CDT, as well as the prescriptive methods of instruction developed by Gagne', Merrill, Briggs and others, attempted to address the issues of developing all forms of instruction. These methods are founded on an instruction design process founded upon cognitive learning principles. Basic precepts of the prescriptive approach are:

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1. Recognition that various learning objectives represent distinct learning outcomes that may require different teaching strategies and presentation methods.
2. Improved understanding of cognitive processing that underlies knowledge acquisition and skilled performance in any specific learning domain.
3. Use of explicit methods to promote learning by providing features of instruction, including performance knowledge organizers and/or task information templates, verbal prompting and immediate performance feedback and knowledge of results, to help the learner more efficiently process and acquire the knowledge and skills desired

Prescriptive methods of instruction have focused almost exclusively on the cognitive domain. Instructional prescriptions for complex skills have not been as well developed, so one must look to a body of scientific knowledge accumulated largely from laboratory studies in human performance. It is presumed that prescriptive methods can be derived from such studies, if reliable and valid conclusions can be drawn from the research in human performance and learning.

Methods for Improving Instruction of Perceptual-Motor Skills

Much of the early literature in perceptual-motor learning was heavily influenced by behavioral methodology developed in the psychology laboratory, with concentration in such areas as practice length and distribution, sensory feedback and knowledge of results, and various methods of response reinforcement (Bilodeau, 1966, Adams, 1968). There was a definite shift in focus from the behavioral to the cognitive approach to the study and understanding of complex perceptual-motor skills beginning in the late sixties.

Fitts and Posner (1967), for example, postulated that there were "sensor-motor" schemas that served as organizers and controllers of complex skills. These schemas were thought to operate much like a stored computer program and their operation accounted for the so-called automatization of complex skills. Fitts and Posner also recognized the important influence that cognitive training for learning the structure of the perceptual-motor skill, and the importance of corrective feedback of performance during practice trials.

Gibson (1966), who had a very prominent influence in the area of perceptual learning for aviators, observed that pilots during early flight training were easily overwhelmed by a cascade of "spinning instruments", but eventually learned to process and interpret both instrument and out of cockpit cues with ease. He postulated a theory of perceptual learning based upon the experience gained while practicing the task and observing the relationships between environmental cues and successful responses to cues perceived as relevant to aircraft control or flight status. The learner, in effect, while practicing a complex perceptual motor task, gradually learns what cues are important to attend to. Gibson suggested those experienced pilots, or instructors, could speed this learning process by highlighting the important cues, and demonstrating the relation between cues and responses by the learner.

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Merrill (1971) places emphasis on the importance of perceptual discrimination and correct response chaining during complex perceptual-motor learning. The chaining of response sequences are combined to form the required tie between perception and movement behaviors required for skilled performance. In order to promote learning, he recommends prompting the correct response, providing knowledge of results, reinforcing correct responses and response topography, making cues more distinctive, use of verbal prompting, and demonstration of a skill performed by an expert.

Bailey, Hughes and Jones (1980) were successful in using the behavioral method of "backward chaining" part-task training while teaching US Air Force pilots dive bombing. This technique was also used successfully by Wightman (1983) to teach Navy pilots' carrier landing skills. The backward chaining approach involves teaching the terminal segment of a sequential task first, and then backing through the task sequence until all task components have been mastered. This approach is accepted practice by many trainers, and fits well with tasks like carrier landing and dive bombing which are clearly sequential and easily segmented for a part-task training approach.

Various methods of performance feedback have been studied as a means to improve performance and learning of perceptual motor skills. These studies include those that provide concurrent feedback to learners during skill acquisition, and those that provide after action knowledge of results. The influence of feedback on learning complex perceptual-motor skills as been very inconsistent and is sometimes difficult to interpret or apply directly to training. Schmidt and Wulf (1997) reviewed literature on the topic of concurrent feedback and conducted experiments designed to improve our understanding of perceptual-motor learning under various feedback conditions. Subjects performed a laboratory task (lever positioning) with visual feedback, when provided. The researchers were interested in a better understanding of many studies that showed that concurrent feedback often helped performance during task practice trials, but the performance gains were temporary and did not transfer to the operational task when feedback was removed. In other words, the feedback affected performance but did not have a permanent effect on learning. One possible explanation for this finding is that the concurrent feedback essentially functions as a "crutch" used to produce the correct responses during practice trials, and when removed the learner can no longer perform the task at the required level. Another explanation for the lack of "learning" transfer is that the learners' attention is focused on the augmented feedback and therefore may fail to concentrate on the most important relationships between naturally occurring cues and the associated correct responses. Experiments performed by Schmidt and Wulf (1997) supported findings of earlier studies by Schmidt (1991), and Schmidt, Bjork (1992) which showed performance gains for concurrent feedback during practice trials, but no learning effects.

The current study by Schmidt and Wulf concluded that use, or misuse, of concurrent feedback during some forms of perceptual-motor learning may actually impair learning. Their findings seem to match others who have studied the complex effects of feedback and knowledge of results on perceptual-motor learning.

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Salomoni, Schmidt, and Walter (1984), after conducting a comprehensive literature of laboratory studies of results and motor learning, concluded that the effects of performance feedback in many cases drop out following the acquisition phase of learning. In other words, feedback provided during practice may have temporarily enhanced performance, but the advantage was not sustained in follow on learning transfer and retention tests. Similarly, Nishikawa (1985) found that many of the immediate feedback studies he reviewed indicated that immediate feedback during practice trials mostly affected performance but had little or no impact on the eventual learning of a complex skill. He did find that some forms of feedback were effective, but the effectiveness depended upon the type of task, the nature of the feedback, and the learning state of the learner at the time feedback was provided. Cohen (1985) shed some light on the inconsistency of feedback application by suggesting that feedback is most useful during early learning phases, and that one should consider the timing and content of feedback required. Cohen believed that feedback in computer-aided instruction should let the student know whether a given response is right or wrong, and also provide information about how to locate and correct errors.

Various methods for practicing key components of a complex skill have been attempted to improve learning and retention. Wightman and Lintern (1985) reviewed much of the literature on part-task training and established a clear framework relating the types of part-task variations and methodologies for separating performance from learning effects. These authors concentrated on manual control task studies and various methods for decomposing tasks, as defined below:

- Segmentation, which is partitioning components of a sequential skill
- Fractionation, which is separating elements of a time-shared task
- Simplification, which is making difficult tasks easier by slowing pace or reducing information flow
- Augmented feedback, which is highlighting or adding supplementary cues to stimulus environment

Wightman and Lintern concluded that the only consistent positive results were obtained using the segmentation method, such as the backward chaining techniques used by Bailey, et al. (1980) cited earlier. Wightman (1983) used the backward-chaining method and showed positive transfer of learning to an aircraft-landing task. Fisk, Scerbo, and Schneider (1983) and Schneider (1985) argue that training on a whole task in a “natural” setting is inefficient in many cases because the real world does not typically expose the learner to consistent task elements. These authors recommend (1) isolating consistent task elements for focused practice (2) providing an opportunity for repeated practice with feedback, (3) practicing critical task components separately to reduce information overload, (4) training to an acceptable level of accuracy, and (5) incorporating extrinsic motivating conditions and learning incentives (isolating consistent task elements for focused practice).

Another strategy for teaching complex skills is to adapt the difficulty of a task to the learner's skill level. During learning acquisition trials, the task is simplified through such techniques as slowing the required response time, or made easier by providing augmented feedback, verbal prompting or cue enhancement. This method is referred to as adaptive training. Adaptive

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training originated in studies of manual tracking (Kelly, 1969), and has been proposed as a means to accommodate individual differences in learning rate, as well as for providing differential feedback at various learning stages during skill acquisition.

The adaptive training process is one in which the presentation of instruction is varied in accordance with student learning rate. A computer algorithm determines presentation rate that is governed so that task speed, or difficulty, progressively increases with improved task performance. In a study of perceptual-motor skill acquisition, Mane' (1984), compared the effectiveness of adaptive training to a part-task training method. The task studied was a video "space fortress" game in that simulated a surface ship warfare mission, including tactical situation and weapon launch. Mane' used a slowed down version of the task for beginners as an adaptive training strategy, increasing the speed as learners progressed.

A second part-task strategy was also tested in his experimental framework. He allowed this treatment group to practice critical elements of the task separately prior to transfer to the whole task. A control group practiced the whole task at a constant (normal) speed. Mane' held the view that part-task training, exemplified breaking the task into basic components and then allowing the learner to practice each task separately, enabled learners to concentrate on important variables associated with successful performance.

The results of Mane's experiments clearly and significantly showed the superiority of the part-task method in his particular study application. In another similar study, Wightman and Sistrunk (1987) studied the use of adaptive and part-task training strategies on an aircraft carrier landing task, using task simplification or progressive difficulty and a part-task strategy (segmentation). Wightman and Sistrunk reported that there was significant advantage for both low and high aptitude subjects using the part-task segmentation method, compared to the adaptive training (progressive difficulty) method.

It may be postulated that motor skill learning, like cognitive learning, is founded on the development of "generalized schema" that govern the transfer process and affect the speed of learning new skills. This postulate implies that systematic variation in task demands and the stimulus environment during training trials help to establish and solidify developing schema for improved perceptual-motor acquisition and retention. A number of studies following Mane's 1984 study, using the Space Fortress video game appear to support this reasoning. Gopher, Weil, and Bareket (1994) summarize the findings of these studies, and present some experimental evidence that general attention control strategies can be trained using video games, like Space Fortress, and that such pre-training shows positive transfer to flight training tasks performed in a flight simulator and aircraft. In this case, trainees practice handling information overload and to establish successful task prioritization schemes that work well in performing the tactical tasks of the Space Fortress game (moving a vehicle to gain tactical advantage, and accurately firing simulated weapons). Results of the study showed that students trained on the video game had a clear advantage during later flight training.

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Recently researchers have begun identifying the neurological foundations for motor skills and motor skill learning. Willingham (1999), for example, reported findings from neurological experiments and case studies (some done with positron emission imaging of the brain anatomy) that show underlying brain structures involved in different levels of motor response processing. Willingham supports views regarding underlying information processes that include (1) a strategic (thinking and goal selection) neural process, (2) a perceptual-motor integration process, (3) a motor response sequencing process, and (4) a dynamic process that accounts for learning new motor actions associated with perceptual cues. He then identifies hierarchical neurological structures that form the substrate for both conscious and unconscious, or automatic, perceptual-motor control actions.

Adaptive training is considered another form of feedback to the learner during application, and therefore poses some of the same issues regarding the content, timing, and format of such feedback options and their effects on the learning process. Application of various forms of feedback, including knowledge of results, augmented cueing, verbal prompting, task difficulty adjustments, etc., appear to play a multifunctional role, acting to motivate, reinforce, and to inform the learner. Effective use of feedback, however, depends on the nature of the task, the state of the learner, and the method and timing of delivery. It appears from the evidence, that augmented feedback during practice of complex skills can improve learning. But only if it is applied on tasks known to depend on external cueing for response guidance, if learners have not attained mastery, and if used sporadically, and if augmented feedback is eventually withdrawn to reduce dependency prior to transfer to the operational task.

It is clear from the literature that conditions that might improve performance during practice do not necessarily result in better learning. Variables such as distributed practice, sessions, extra practice opportunities (over learning), and augmented feedback have had mixed results regarding their permanent effects on learning as measured by learning retention and transfer (Swezey and Llaneras, 1997).

Various approaches have been taken to improve perceptual-motor training using cognitive instruction. Singer, Korienek, and Ridsdale (1980) investigated the effectiveness of various cognitive strategies. These strategies included imagery rehearsal, chunking, rote verbalization, and informed choice (p.97). The serial manipulation task studied required the learner to correctly perform a sequenced response selection, like lever positioning that was followed by feedback. In the chunking condition, subjects were instructed to group responses into a sequence of three. For the rote memorization treatment, subjects performed the task sequence while verbalizing their responses.

In the imagery condition, subjects were asked to mentally picture responses that are logically categorized into storage bins. Informed choice consisted of one or all-previous strategies, self-selected by subjects. A control group received no instructions. None of the purported cognitive strategies appeared to support the hypothesis that predicted better performance of chunking and imagery methods over rote verbalization. The authors discussed the difficulties of defining and testing such strategies, based upon theoretical instructional expectancies.

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On the other hand, some cognitive instructional strategies have resulted in improved perceptual-motor training. Landeweerd, Seegers, and Perryman (1981) found the use of a process-oriented approach rather than an ordinary input-output information approach was superior for training chemical equipment operation.

It was easier to train operators who were given flow chart information depicting the process underling the chemical plants equipment operation. Myers and Fisk (1987) conducted a series of experiments designed to investigate the application of Shiffrin and Schneider's (1977) theory of automatic and controlled processing. One major hypothesis of this study that was supported is that high performance skills develop through extended practice of consistent task components. As skill develops expert performance is typically controlled through automatic processing.

Smith (1984) was also interested in application of contemporary cognitive and information processing theory to complex skill training. He studied the effects of the presentation order of cognitive training on a flight task. To assess order effects, Smith presented information about the cognitive aspects of a basic flight maneuver at various times in the flight training sequence.

Four groups of volunteer subjects were used in the study. The first group was given extensive cognitive training prior to undertaking the motor task. The second group received the same extensive cognitive training as group one but also received some cognitive training during motor skill acquisition. The third group received no cognitive training prior to the motor test, but received sporadic cognitive instruction during motor acquisition. The fourth group, serving as control, received no specific cognitive training, but was only given motor skill instruction.

The results of this study showed clearly, that group one, who received the cognitive training prior to undertaking motor skill training, performed significantly better during later motor skill practice trials. Groups two and three, using sporadic cognitive training during motor skill acquisition showed the poorest performance. The authors concluded that providing cognitive instruction during motor skill acquisition trials might actually impair performance.

Goettl and Gomez (1995) conducted experiments to determine the effectiveness of "observational learning" in computer-based simulation learning. Observational learning takes different forms, but basically the term refers to learning that takes place during passive observation of task performance, such as that provided by an instructor's demonstration of a complex task. As originally outlined by Bandura (1986) learning is thought to depend upon such factors as, motivation, attention, and the individual processing of critical features of the task during the period of observation. A behavioral production process is hypothesized to account for the transformation of cognitive learning attained during observation to performance on the perceptual-motor task components. Carroll and Bandura (1995) further stipulated that if the spatial and temporal features of the task can be easily extracted and coded, there will be little need for overt practice (Goettl and Gomez, 1995, p. 1335). The experimenters, Goettl and Gomez, set out to demonstrate that observational learning would be more beneficial in situations that can be symbolically coded than for tasks that cannot. They predicted that flight simulation

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tasks that have a substantial cognitive component would benefit more from observational learning than tasks that are substantially perceptual-motor in content.

The results of a series of interlocking studies, using various cognitive and perceptual-motor tasks and observational learning strategies, were consistent with other research findings that showed that observational learning was most useful for tasks with high cognitive demands than those tasks that are primarily perceptual-motor. These findings are also consistent with the theories of skill acquisition that suggest the initial stages of complex perceptual-motor skills focus on cognitive or declarative knowledge (Anderson, 1982; 1981).

The emphasis on observational learning made by Bandura and others may be best placed on the front of the skill acquisition process while the learner is still attempting to understand the elements of the tasks through a more cognitive problem-solving approach.

Prescriptive Methods of Instruction for Perceptual-Motor Learning

As was discussed in an earlier section, the Component Display Theory of instruction is a detailed methodology for teaching cognitive skills. This narrow focus, however, limits the direct application of CDT to teaching perceptual motor skills, including the operation of complex equipment, such as flying an airplane. Ciavarelli (1988, 1987) recommended that CDT be expanded to include instructional prescriptions and assessment methods for complex perceptual-motor skill training. He constructed a combined task classification and performance matrix and an instructional design framework for the complex –perceptual-motor learning domain. The extension of CDT to the perceptual-motor domain was accomplished by expanding the learning outcome categories originally proposed by Merrill (1983), an incorporating appropriate instruction presentation strategies, learning aids, and assessment methods. A basic outline of this methodology is presented below. Clarification and additional narrative to the tables and bullets presented below will be provided during a second phase of the SBIR program.

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Extended CDT for Complex Perceptual-Motor Skills

Task Performance- Perceptual Content

	Signal	Spatial Pattern	Temporal Pattern
DETECT			
DISCRIMINATE			
RECOGNIZE			

Motor Task Classification

	Whole Task	Part Task
Self-Paced or Untimed		
Externally-Paced or Timed		

Primary Instructional Presentation Strategies

Primary Presentations

	Whole	Part
DEMONSTRATION		
PRACTICE		

Secondary Instructional Presentation Strategies

- Advance Organizers
- Cue Enhancement
- Verbal Prompting
- Performance feedback

The instruction model proposed, like CDT for the cognitive domain, defines specific content and task performance categories as defined below:

Perceptual Content

- Signals: single elements of information that can be distinguished from surround or background.
- Spatial: arrangements or arrays of patterns of signals or objects
- Temporal: correlated time-event sequences or sequence patterns

Performance Levels for Perceptual Skills

- Detection: sensing the presence or absence of a specific signal or pattern
- Discrimination: distinguishing relevant signals and patterns from non-relevant ones

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- Recognition: automatically responding to specific signal categories or patterns

Motor Task Content

- Discrete task: a task with an identifiable beginning and end point (e.g. hitting a baseball)
- Sequential task: a series of discrete motor tasks performed in a specific order (e.g. shifting a five-speed automobile or truck transmission).
- Continuous task: requires continuous motion from start to end of task performance, and typically is guided by external feedback cues (e.g. manual tracking or steering a vehicle)

Performance Levels for Motor Skills

- Self-paced: operator can control the speed of presentation and input (and work at own pace)
- Externally-paced: the speed of the presentation and response time of the operator is governed by the system or environment

The extended CDT approach described here presumes that the learner has completed the cognitive segment of instruction related to the perceptual-motor skill using prescriptive methods of instruction described previously. The cognitive instruction should take place prior to commencing perceptual-motor training. The learner should be taught the nature of the task (facts about operating system, performance conditions and environment), shown examples of information flows, salient perceptual cues, and given some instruction about associated facts, concepts, principles and procedures, and performance requirements. Some examples that illustrate the combined Cognitive and Perceptual-Motor CDT instruction are provided below:

EXAMPLES OF LEARNING OBJECTIVES AND INSTRUCTIONAL METHODS

(To be completed for various Hover Training Tasks)

1. Stationary hover: hover 3ft. Behind a Maltese cross, in alignment with the runway, at a skid height of 3-5 ft.
2. Hover taxi: Taxi down the centerline of the runway at a skid height of 3-5 ft at a speed not to exceed that of brisk walk.
3. Hovering turn: Maintain the aircraft over a fixed point on the runway at a skid height of 3-5 ft.; perform pedal (yawing) turn to the right; perform 90 degree pedal turn to the left to return to initial heading.
4. Land from hover: Smoothly reduce collective pitch to land from a stationary hover, maintaining alignment and position over the ground
5. Takeoff to hover: Smoothly increase collective pitch to bring the aircraft to a 3-5 ft hover maintaining runway alignment and position over the ground (Dohme, 1994, p.117)

Cognitive Training Segment

1. Learning objective and Performance Level
2. Primary Cognitive Instructional Presentations (Rule, Examples, Practice, and Test)
3. Secondary Cognitive Instructional Presentations (Organizing Templates, Prompts and Guidance)

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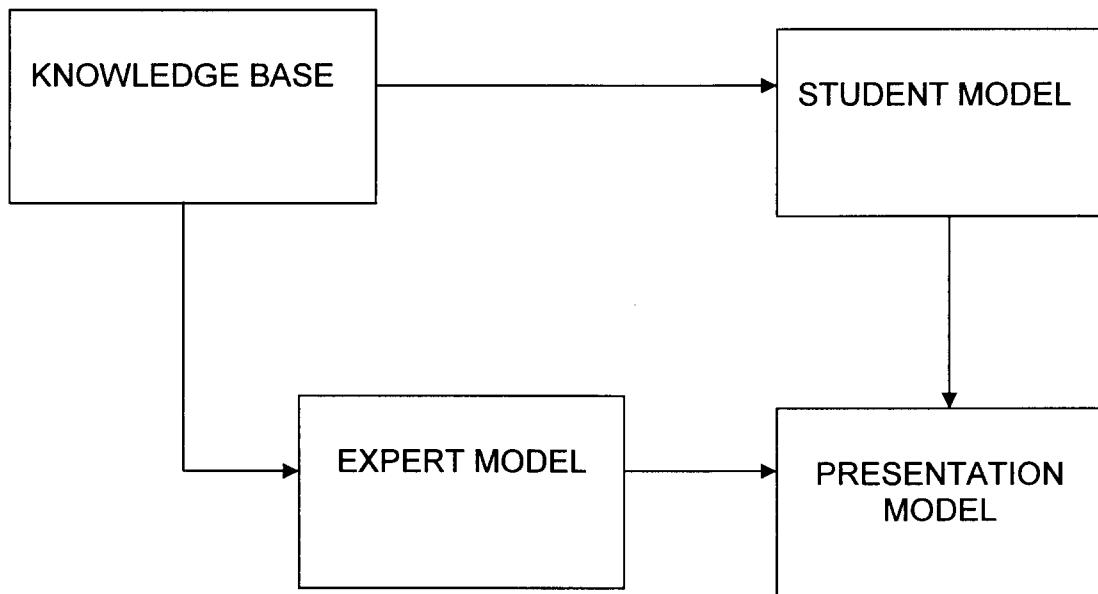
Perceptual-Motor Training Segment

1. Learning objective and Performance Level
2. Primary Perceptual-Motor Instructional Presentations (Instructor Demonstrations, Guided Practice, After Action Feedback)
3. Secondary Perceptual-Motor Instructional Presentations (Cue Accentuation, or Highlighting, Adjustment of Task Difficulty and/or Information Flow, Instructor Real-time Assessment and Guidance).

EXPERT TUTOR SYSTEM

An Expert Tutor System has an ability to infer the state of knowledge and intentions of the student and tailor its pedagogy, instruction, and presentation to accommodate the user. In order to do this, the system needs to create and maintain a student model of the current user as depicted in Figure 1. An expert model is used to generate inferences about the student's state of knowledge represented in the student model. A presentation module would use the results of this inference "engine" to make decisions on what material, or task performance level to present to the learner, and how best to present that material or task simulation.

Figure 1: Basic Intelligent Tutoring System

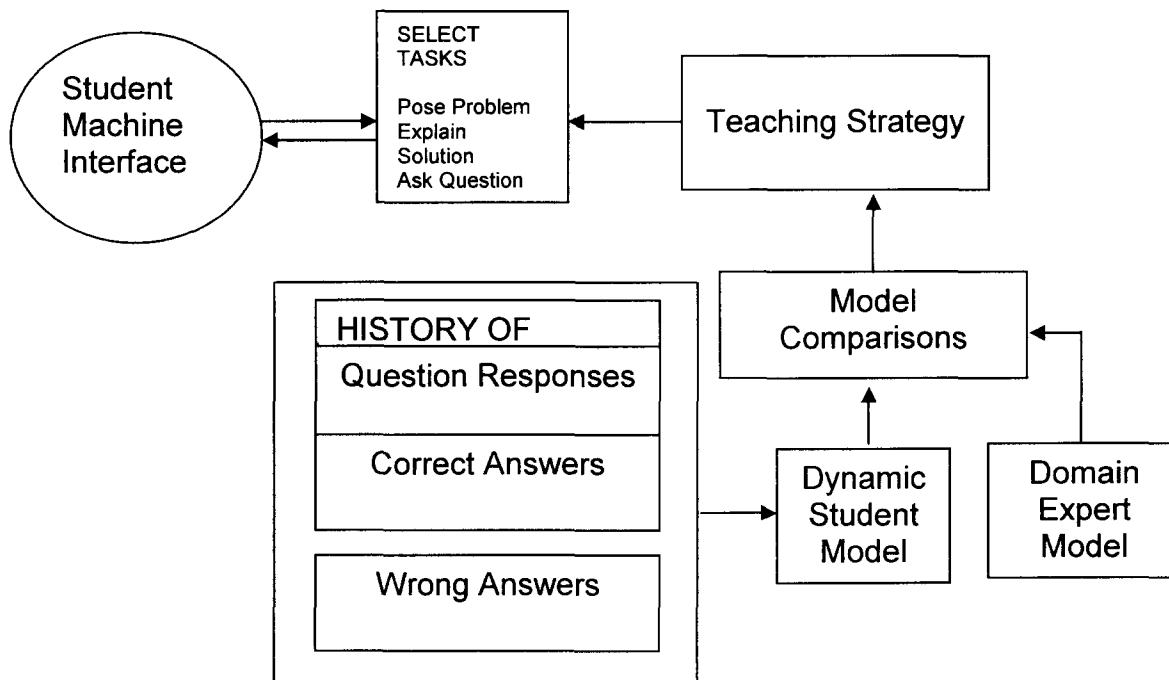


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The inference engine is based upon the use of artificial intelligence, or in this application referred to as an expert system. An expert system is a software program that uses artificial intelligence techniques for reasoning with data and drawing appropriate inferences about instructional strategies based upon a student's profile characteristics and performance on a particular task or set of tasks. Expert systems come in several different variations, depending on the structure of the knowledge base (rules, frames, or semantic networks), the method of reasoning (forward chaining or backward chaining), ability to handle uncertainty (Bayesian reasoning, probabilistic models, or fuzzy logic).

Mulgund, Asdigha, and Zacharias (1995) presented a refined and expanded architecture of a general intelligent tutor as depicted in Figure 2, below:

Figure 2: Basic Intelligent Tutoring System (Mulgind, Asdigha and Zachariaas, 1995).



Dohme (1994) became interested in improving training for beginning US Army helicopter pilots and argued for the application of sound instructional principles. His outline of key learning processes is presented below:

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Summary of learning processes for skill development (Dohme, 1994, p. 51)

1. An indicator on which the activity-relevant indication appears (stimulus) (e.g., instruments, warning lights, and horns.)
2. A cue, or sign that calls for a response (decision to make corrective action) (e.g. checklist, instrument reading different from expected, flashing light, a special sound).
3. A control object to be activated (e.g. aircraft yoke, throttles, rudder pedals).
4. The activation or manipulation to be made (actual behavior sequence in executing the selected motor action) (e.g. push forward, pull back, turn clockwise).
5. The indication of response adequacy (e.g. instrument reading normal, glide -slope indicator or showing on glide slope, flashing light goes off).

Dohme suggested that an Automated Helicopter Hover Trainer be developed based upon our understanding of how best to teach hover tasks. He made the following key points in his analysis (Dohme, 1994, p. 115).

Key points:

- Hovering is one of the key skills learned by ab initio trainees.
- Stationary hover, hover taxi, hovering turns, and takeoff and land from hover must be mastered before a helicopter pilot can solo
- Hovering requires the coordinated use of helicopter flight controls
- Pilot must learn to ‘overcome the interactions built into the aircraft
- Learning to hover as been traditional “monkey see monkey do” approach, in which instructor pilot demonstrates a maneuver and then the trainee performs the maneuver while the IP monitors and guides performance.
- Pilot must learn to maintain the aerodynamic balance required for stable flight.
- This requires the pilot to attend to specific cues and to make small but accurate control inputs to maintain a constant position over the ground.

Dohme (1994) stated that, “A simulator-based trainer is envisioned that would continuously review trainee performance and adaptively augment control inputs such that the demand characteristics of the simulator would accommodate the trainee’s ability to successfully hover (p. 116).” A prototype was developed and tested in a series of experimental training transfer studies. The automated hover trainer used a mathematical model that compared trainee performance against “expert performance norms” that were derived from analysis of maneuvers performed by highly experienced pilots. The computer program ‘adapts’ to the learners performance by reducing the control augmentation as the performance improves up to the standard (i.e. the student is performing to the level defined in the unaugmented helicopter aerodynamic model).

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Intelligent Flight Trainer

This SBIR project completed by Mulgund, Asdigha & Zacharias (1995) set out to integrate intelligent tutoring with PC-based flight simulation. IP domain knowledge was incorporated into an expert system with the intent of providing intelligent corrective feedback to the trainee. The feedback was represented by verbal comments using a voice synthesizer. Both procedural cueing on “proper maneuver execution”, and comments regarding “manual task performance” were provided.

Some of the key functional characteristics of the IFT baseline system include (p. 1)

- A tutorial function to remind the student how to implement good perceptual or control strategies (e.g. “Remember to apply left pedal as you raise the collective.”).
- A performance monitoring function for performance advisory messages (e.g., “You are too high.”).
- A control activity monitoring function to provide feedback on the student’s control usage (e.g. “You are thrashing the collective.”).
- An advisory function that makes explicit the suggested control strategy or corrective maneuvering (e.g. “Slow down using aft cyclic.”).

System design software components included, a rule base, a message database, and adaptive control logic that governed the hover maneuvers. The IFT determines stability augmentation needed on the basis of performance monitoring, and then sends inputs to the host simulator for controlling helicopter flight dynamics. Cockpit displays are updated as soon as flight dynamics data are available to the simulator host.

Mulgund, Asdigha, and Zacharias (1995) summarize a Phase II SBIR effort for development and validation of an Intelligent Flight Trainer (IFT). The IFT is a PC-simulator system used to teach beginning rotary-wing students basic hover maneuvers. This trainer includes an expert system representing the instructor pilot (IP) that presents feedback to students during practice of hover maneuvers using synthetic voice. The expert system shell drives a variable stability augmentation algorithm that adjusts the difficulty of helicopter motion control, to make it easier for the novice to maintain stability and control of the vehicle. The IFT was completed and major functional performance areas were demonstrated, including adaptive aiding that varied task difficulty, IP performance diagnosis and generation of student advice, and use of synthetic voice feedback system. The IFT study report (Mulgund, Asdigha, and Zacharias, 1995), recommended that follow-on efforts be undertaken as follows (p. v):

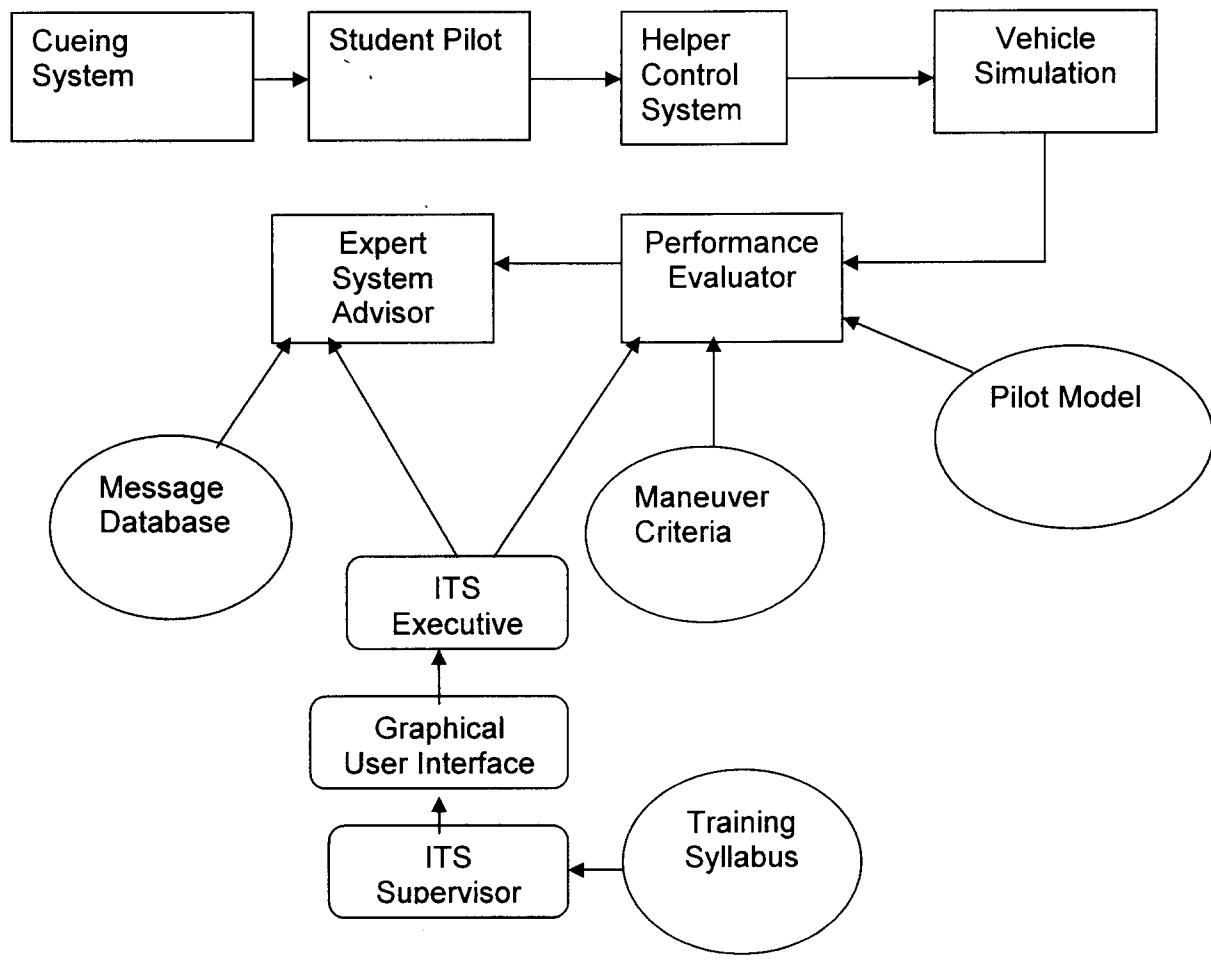
1. Conduct a formal validation and transfer experiment.
2. Transition to the TH-67 helicopter.
3. Develop training modules to include other flight tasks (level flight, climb, turns, descents, etc.
4. Install all system components on a single PC (rather than linked PC’s as is current baseline system is configured now).

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Other recommendations include the inclusion of graphic augmentation and feedback, including the possibility of using a “highway in the sky” display, and using visual display cue augmentations such as highlighting or pointing to important display data elements.

The functional architecture of the IFT is shown in Figure 3, below.

Figure 3: Baseline one: Intelligent Flight Trainer (Mulgund, Asdighi and Zachariaas, 1995).



The simulator host models the 6-degree of freedom dynamics of a Bell UH-1 (Huey) helicopter developed at the University of Alabama Flight Dynamics Laboratory (Mulgund, Asdigha, & Zacharias, 1995, p. 14). Two major computational models are used in the IFT.

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1. *Expert System Advisor* that uses instructor pilot knowledge to produce feedback on manual flight performance and corrective piloting techniques.
2. *Adaptive Helper* that provides vehicle dynamics stability augmentation to adjust control task difficulty to match a particular student's skill level.

The domain knowledge uses a CLIPS rulebase developed by NASA to help model human knowledge or skill (Giarratano, 1983). A complete description and mathematical model definition is presented in Mulgund, et al. and will not be repeated in any great detail here.

Briefly, the *Expert System Advisor* provides verbal feedback to the student using a synthetic voice system. Feedback content and format varies as follows (p. 15):

- A tutorial function to remind student how to implement good perceptual or control strategies (e.g. "remember to apply left pedal as you raise the collective.")
- A performance monitoring function for performance advisory messages (e.g., "You are too high.").
- A control activity monitoring function to provide feedback on the student's control usage (e.g., "You are thrashing the collective.").
- An advisory function that makes explicit the suggested control strategy or corrective maneuvering (e.g. "Slow down using aft cyclic.").

The expert system provides appropriate feedback based upon student performance on the task, and informs the student of any changes in help function adjustments.

Again briefly, the *Adaptive Helper* generates "inner-loop" stability augmentation to facilitate student control of the helicopter and assist in performing a particular maneuver. The strategy used by the adaptive helper is based on modeling the student pilot and the expert pilot using methods developed by Kleinman, Baron, & Levison, (1970) and referred to as the *Optimal Control Model*.

The system supports aided training on such tasks as: *fixed hover* (student maintains the helicopter in a fixed position over the runway), *hover taxi* (student begins at a fixed point and hovers down runway centerline for a defined distance), *hover turn* (the student makes alternating right and left turns while maintaining fixed coordinate limits), *traffic pattern* (the student flies a rectangular flight pattern near the runway), *accelerate to lift off* position (student accelerates down runway centerline and maintains lateral and altitude flight parameters to lift off point), and for takeoff and landing from a hover. More complete information on mathematical models, hardware and software implementation of the models, control programs, and simulator is presented in Mulgund, Asdigha, & Zacharias (1995).

Monterey Technologies, Inc

Skill training requires both instruction and the opportunity to practice the task. One method of instruction would be to provide "show and tell" guidance initiated by an external agent based on the presumed or perceived needs of the student. Instruction facilitates learning but is not an

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essential element of the learning itself. Feedback is the immediate and direct sensory and perceptual consequences of the student's actions (or inaction) and is an essential element of the learning process. Skill acquisition depends on the feedback gleaned from frequent and consistent pairings of actions with external event outcomes. An after-performance critique is often referred to as feedback, but is really a performance history based upon recently completed behavior. This critique usually is intended to instigate a modification of the student's behavior during the next training exercise. Instruction during student performance is an abbreviated, short cycle of instructional critique and not a form of feedback. Figure 4 shows a schematic model of a typical training process. Note that the instructor must both assess the skill level of the student and make recommend any changes to either the feedback received by the student or the instruction given to the student.

Figure 4: Alternate Baseline Intelligent Tutor. Initial baseline presented by Monterey Technologies, Inc. (SBIR Proposal, 1999).

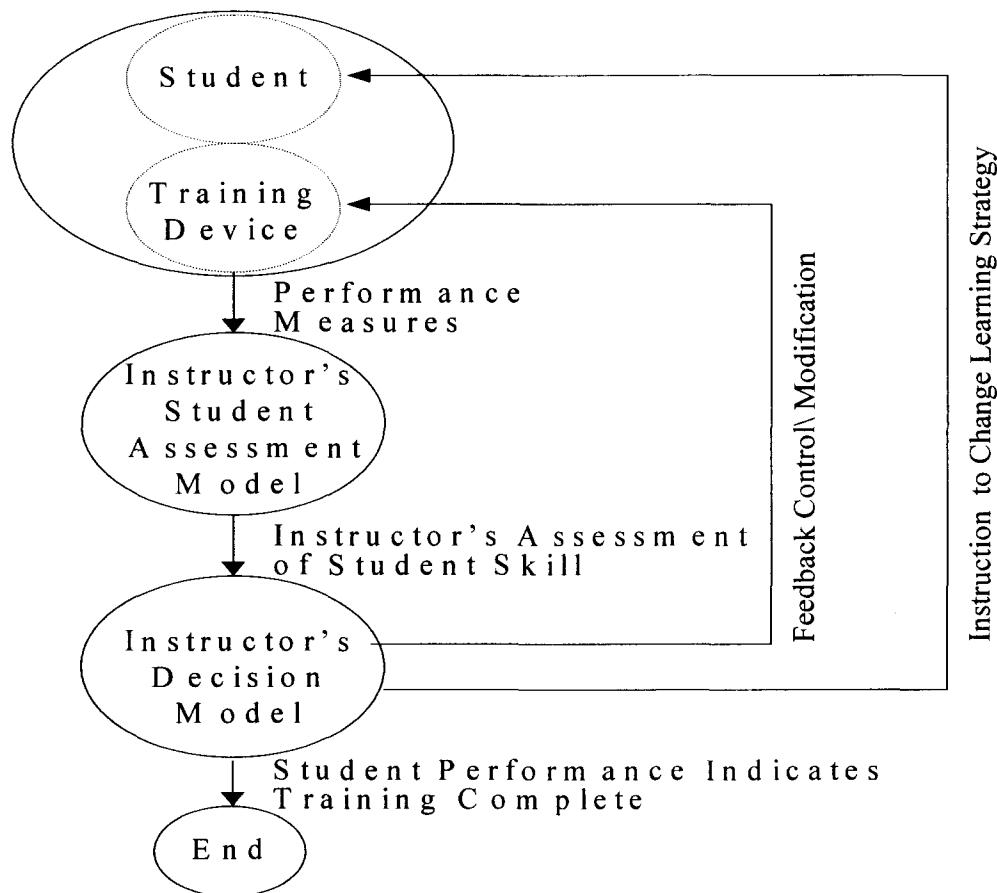
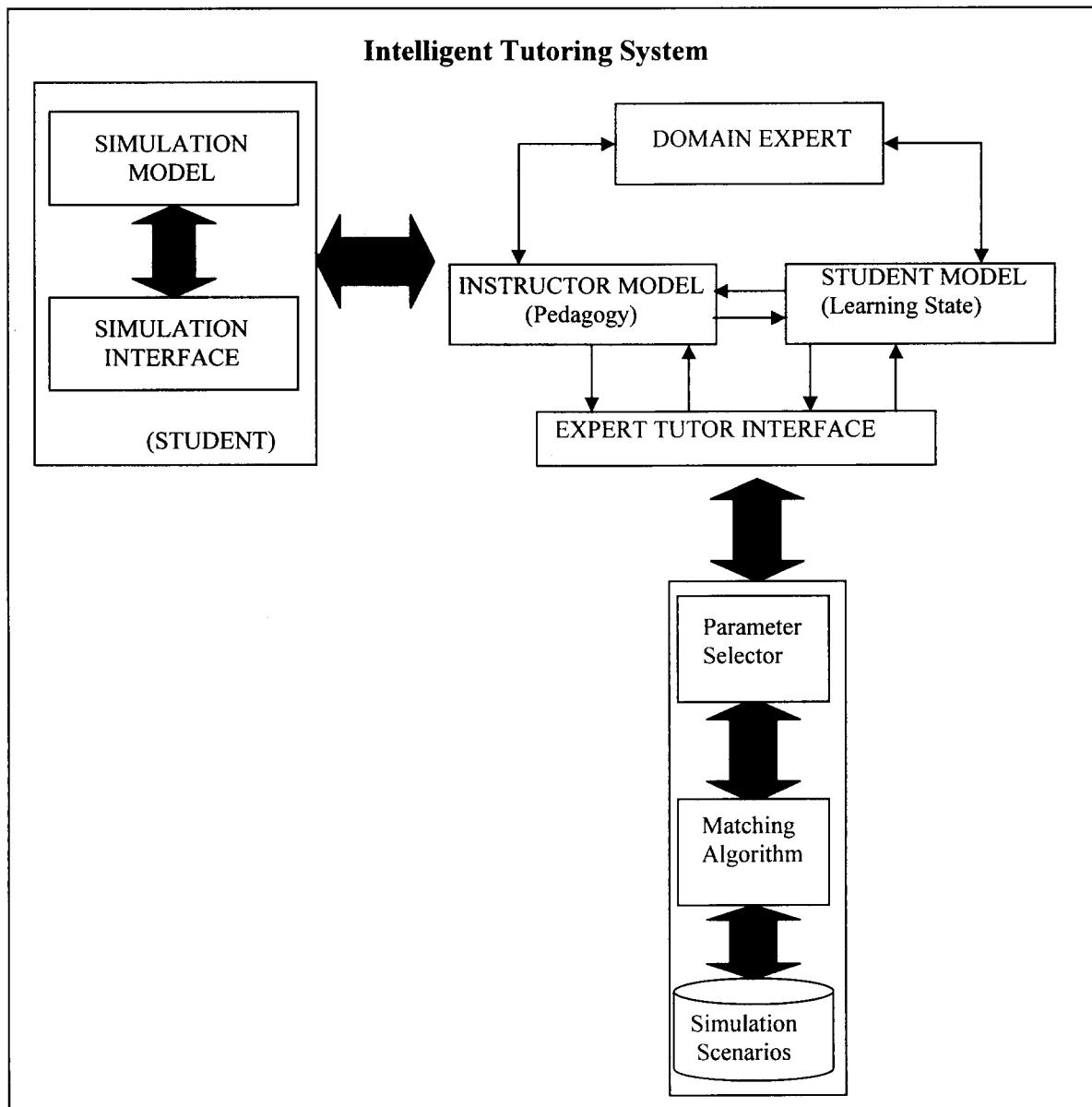


Figure 5 presents an evolved version of Figure 4 with the live instructor replaced by a model and a model of the student added to allow interpretation of the performance and learning processes of the student. The key feature of this tutoring system is its dependence on behaviorally based models of learning, performance and instruction that are open to scrutiny and modification.

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Figure 5: Baseline 3. Intelligent Tutor (Chappell and Mitchell, 1997).

BUILDING A KNOWLEDGE RULEBASE

Limitations

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Sleeman and Brown (1982) raised several important issues regarding the use of intelligent tutors, following a review of artificial intelligence (AI) applications to instruction, and early versions of tutoring systems. The limitations outlined by these authors is worth keeping in mind today, in spite of the many improvements in AI, and computing technology available now.

1. The instructional material produced in response to a student's query or mistake is often at the wrong level of detail, as the system assumes too much or too little student knowledge.
2. The system assumes a particular conceptualization of the domain, thereby coercing the student's performance into its own conceptual framework.
3. The tutoring and critiquing strategies used by these systems are excessively ad hoc reflecting *unprincipled* intuitions about how to control their behavior.
4. User interaction is still too restrictive, and limits the student to work with the ability of the tutors diagnostic mechanisms (Sleeman & Brown, 1982, p.3).

One of the primary limitations of AI applications to instruction mentioned by Sleeman and Brown, and still operative today, is the lack of a consistent set of learning principles and precise domain knowledge on which to construct rule based systems that fully represent the student and the instructor.

Knowledge base for Perceptual-motor Learning

Information extracted from the literature in perceptual-motor learning and some findings from the cognitive learning literature are summarized in Attachment B. It is intended that the summary provided in Attachment B serve as a point of departure for generating a rulebase of pedagogy for teaching complex perceptual motor skills, and is particularly applicable to flight instruction.

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ATTACHMENT A
SYNOPSIS OF SELECTED REFERENCES

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REFERENCE SYNOPSIS

Ackerman, P.L. (1983). A theory for predicting ability/skill relations: An approach from automatic and controlled processing. In, Proceedings of Human Factors Society—27th Annual Meeting.

ABSTRACT: Studies related to perceptual-motor learning are reviewed and discussed. The authors propose a general theory of the relationship between abilities and aptitudes. The theory is based upon an understanding of controlled and automatic processing and various cognitive theories.

KEY TOPICS AND ISSUES:

1. The general theory proposed by Ackerman, in part, accounts for the common finding regarding changes in the inter-correlation between early learning trials and late learning trial performance scores.
 - Patterns of correlation coefficients change substantially over the course of training.
 - Typically measures of cognitive ability correlate highly with initial training, but then decline in magnitude as training on an operational task continues.
 - One interpretation of this correlation pattern is that cognitive components of the task are more influential during early skill learning, and that perceptual-motor components have greater influence as learning progresses.
2. The theory of controlled and automatic processing proposed by Schneider and Shiffrin (1977) typically observes changes in operator performance characterized by “effortful, slow, and error prone” performance during early training periods, and progressively less effort, improved accuracy, resistance to distraction and a greater level of automaticity in performance, as the operator becomes more proficient.
 - Shiffrin and Schneider refer to these two forms of processing as controlled processing (CP) and automatic processing (AP). Controlled processing is under conscious control, and easily modified during performance. In automatic processing, task performance is largely unconscious and unfolds much like a stored computer program, and hence is less modifiable during task performance.
 - Later studies by Fisk and Schneider (1981) indicate that transformation from controlled to automatic performance described may only be true for tasks that have consistent task elements (in which the operator responds to predictable relationships between perceptual cues and responses).
 - The consistent components of a complex skill stabilize, during early during training and the patterns of correlation due not change appreciably over the course of skill development.

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- Skill automaticity reflects the learners' ability to acquire essential perceptual-motor task components based in internalized relationships between consistent elements of tasks and relevant perceptual cues.

APPLICATION OF FINDINGS

- Instructional designers should attempt to identify cognitive and perceptual-motor components of a complex skill in order to develop effective instructional strategies.
- In accordance with the findings summarized here, it may be most beneficial to offer cognitive approaches early in training, and then shift to perceptual-motor aiding later in the training period.
- Instructional designers should identify context (environmental) cues that are the most powerful in capturing attention and initiating correct or incorrect responses during later periods of training.

RELATED REFERENCES:

Fisk, A.D., & Schneider, W. (1981). Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. *Human Factors*, 23, 737-750.

Fleishman, E.A. (1972). On the relation between abilities, learning and performance. *American Psychologist*, 27, 1017-1032.

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REFERENCE SYNOPSIS

Fisk, A.D., Lee, M.D., & Rogers, W.A. (1991) Recombination of automatic processing components: The effects of transfer, reversal, and conflict situations. *Human Factors*, 33, (3), 267-280.

ABSTRACT: This paper discusses issues related to the automation of skilled performance. The study reports findings of experiments investigating the effects of compatible and incompatible automatic process on performance. Fisk and his associates amplified on earlier work of Fitts (1962, 1967) regarding the automation of skill as a performer moves from novice to expert. Most skill performance progressively improves in speed and precision, as well as a reduction in attention resources required for a given task. A skilled performer appears to perform complex tasks quite effortlessly after substantial practice. Fitts and his colleagues have identified some specific relationships underlying skilled performance that may be useful in establishing principles of learning and performance enhancement. It is strongly implied that the research foundation is well enough established to recommend specific "limits and guidelines" for training.

KEY TOPICS AND ISSUES:

Selected guidelines recommended include (p. 268-270):

- Performance improvements (with practice) will only occur for consistent tasks.
- The type and number of inconsistent task elements limit performance improvement.
- The degree of consistency among stimuli, rules and context are factors to consider in part-task learning strategies.
- Context is an important element affecting skilled performance, in part, because contextual cues may trigger appropriate or inappropriate automatic performance processes.

APPLICATION OF FINDINGS

- Instructional designers should attempt to identify and consider apparent consistencies in the task structure of skills to be trained.
- Instructional designers should identify context (environmental) cues that are the most powerful in capturing attention and initiating correct or incorrect responses during acquisition of skilled performance.

RELATED REFERENCES:

Fisk, A.D., and Gallini, J.K. (1989). Training consistent components of tasks: Developing an instructional system based on automatic/controlled processing principles. *Human Factors*, 31, 453-63.

Logan, G.D. (1988). Toward an instance theory of automatization. *Psychological Review*, 95, 492-527.

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REFERENCE SYNOPSIS

Fitts, P.M. (1962). Factors in complex skill training, In, R.Glaser (Ed.) Training research and education. PA: University of Pittsburgh Press.

ABSTRACT: This paper summarizes early work by Paul Fitts in the area of skill acquisition. Skilled performance is defined as having three key characteristics, spatial-temporal patterning, continuous interactions between input, output and feedback processes, and learning. The basic rudiments of perceptual-motor skill, including basic task taxonomy and characteristics of environmental and internal cues are described. The author discusses the learning of complex skills in terms of "continuous" learning phases, including Cognitive, Fixation, and Autonomous. Paul Fitts was an early pioneer in skill research, and much of the work related to skill acquisition, retention, and measurement of perceptual motor performance is based on his work.

KEY TOPICS AND ISSUES:

1. Components of a complex skill outlined by Fitts include:

- Cognitive -- understanding the structure or nature of the task.
- Perceptual -- learning what to pay attention to, what to look for (salient cue recognition and discrimination)
- Physical Coordination -- integration of perceptual and motor activities (timing of movement patterns).
- Tension Relaxation -- greater relaxation a smoothness and precision with less effort expended.

2. Phases of skill development

- Cognitive -- conscious analysis and verbalization of tasks and cues.
- Fixative or associative -- correct perceptual-motor patterns emerge.
- Autonomous -- the automation of skilled performance, with improved speed, smoothness and accuracy. At this stage of learning there is less conscious control and more resistance to distraction and a shift from external cues to internal (proprioceptive) cues.

3. Task Classification must consider the task and conditions of performance (body position and motion as well as the type and motion of environmental perceptual targets or cues). The most complex tasks are those in which the performer is in motion, and the environment is moving or changing rapidly as well. The following taxonomy presents this particular view:

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COMPLEX PERCEPTUAL-MOTOR SKILL TAXONOMY

	<u>TASK</u>	<u>EXAMPLE</u>	<u>MEASURE</u>
Stationary (BODY)	Discrete	Hitting Ball	(hits/misses)
Moving	Serial	Typing	Rate
	Continuous	Steering, Tracking	Accuracy & Precision

4. In complex perceptual-motor tasks, like flying, the performer must, keep monitor many separate sources of information, and sort out the effects of the changing environment, including those effects produced by the performers own actions.

APPLICATION OF FINDINGS

1. Characterizations of skill taxonomy and learning imply various levels of complexity, and progressive levels of skilled performance.
2. In practice, good instructors understand that teaching complex skills requires different types and levels of information and feedback to the student. So common strategies taken by instructors based upon experience are supported by concepts proposed by Fitts are:
 - Provide students with tutorial information regarding the task structure and salient cues to pay attention to.
 - Demonstrate correct performance to student, showing correct response sequence and timing.
 - Reinforce attention to salient cues during practice sessions, and provide feedback of performance results.
 - As skill becomes more automated, provide less coaching and verbal support during task performance.

RELATED REFERENCES:

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REFERENCE SYNOPSIS

Lintern, G. (1991). An informational perspective on skill transfer in human-machine systems. *Human Factors*, 33, (3), 251-266.

ABSTRACT: This paper discusses skilled performance and transfer from the perspective of perceptual learning theory. The basis for learning and transfer of complex skills is considered to be a performer's attention to specific perceptual patterns or invariants in the stimulus environment, and their relationship to the task. The key theoretical formulation proposed is that both learning and transfer of complex skills is based upon progressive detection and discrimination of critical perceptual cues, stimulus patterns, and important environmental features that serve as external feedback for skilled performance. These perceptual invariants and their positive or negative correspondence among different tasks may account for transfer differential learning transfer effects.

KEY TOPICS AND ISSUES:

1. Transfer of a particular skill depends upon the nature of the task, the control characteristics of the operating device, and the particular design of the human-machine interface.
 - Sometimes skill transfer is negative, that is practice on the first task interferes with performance or delays learning on a second task.
 - Sometimes previous experience on a task improves performance on a second task or facilitates learning a second task (positive verses negative learning transfer)
2. The similarity between tasks (correspondence between stimulus environments and/or response patterns) and task-environment fidelity from a simulated activity to an operational environment are typically proposed to account for positive and negative transfer effects. But it has often been shown that positive learning transfer can occur between tasks that are quite different in composition or are performed in different environments.
 - In some studies, "deliberate departures" from similarity or fidelity resulted in positive transfer effects. Lintern uses the example of training a pilot to land in a cross-wind, and discusses findings from Lintern, Roscoe, and Sivier, (1990) which showed that pilots trained without a cross-wind conditions actually did better on a transfer task that included cross-wind landings.
 - Lintern concludes that transfer effects can not be fully explained using "similar elements" theory, or level of simulation fidelity.
3. Lintern proposes that high-performance skills, in particular manual control skills, are learned through a process of identifying critical features of the stimulus environment that distinguish correct from incorrect performance on a particular task.
4. There is a, "lawful relationship between patterns of stimulation and properties of the task." Some examples of so-called invariants, or stimulus patterns that pilots use are:
 - Motion cues derived from "optical flow", or the relative rate at which a visual scene changes with respect to an aircraft's speed and turn-rate.
 - Size-Distance cues derived from perception of the ratio of runway width to runway length. This is a powerful cue relationship that enables pilots to fly a glideslope, and

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may sometimes lead to common misperceptions of slant range if this ratio is unexpectedly large or small.

4. Learning is a consequence of progressive understanding of the perceptual cues and their relationship to task performance, such that the learner progressively improves in his/her discrimination and extraction of critical information from the environment needed for "expert" performance.

APPLICATION OF FINDINGS

1. Learning and transfer may be improved by helping learner to identify critical features of the stimulus environment that are essential for task performance.
2. Helping learner to identify information and situations leading to error or degraded performance may improve learning and transfer.
3. Simulation devices can include instructional features that enable the instructor to accentuate or highlight specific features of the task and environment.
4. Learning and transfer may be improved by having an "expert" (instructor) demonstrate correct and incorrect task performance, while highlighting associated perceptual cues related to task performance.

RELATED REFERENCES:

Lintern, G., Roscoe, S.N., & Sivier, J. (1990). Display principles, control dynamics, and environmental factors in pilot performance and transfer of training. *Human Factors*, 32, 299-317.

Wightman, D.C., & Sistrunk, F. (1987). Part-task training strategies in simulated carrier landing final approach training. *Human Factors*, 29, 245-254.

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REFERENCE SYNOPSIS

Myers, G.L., & Fisk, A.D. (1987). Training consistent task components: Application of automatic and controlled processing theory to industrial task training. *Human Factors*, 29, (3). 255-268.

ABSTRACT: Two experiments were conducted to examine the generality of automatic/controlled processing training principles to rich, complex tasks. In both experiments, subjects' tasks were modeled after a job function performed by the telecommunications industry. These tasks required subjects to process conjunctions of information. Large quantitative and qualitative differences were found between the consistently and variably mapped training conditions. The need for determining trainable consistent components of complex tasks is discussed (Authors, p. 255)

KEY TOPICS AND ISSUES

1. Most instructional design theories do not fully consider the changes that take place during skill acquisition, and do not provide guidelines regarding proper instructional strategies for different phases of skill development.
2. Schneider and Shiffrin (1977) outlined a theory of skill automation in their descriptions of controlled and automatic performance. Controlled processing is a relatively slow, typically serial, "effortful", capacity limited, and subject-regulated mode. Whereas automatic processing is faster, parallel, not typically under (conscious) subject control, and not as resource limited.
3. Controlled processing is usually applied under conditions that are novel, or during early learning phases, of skill development. Automatic processing typically relates to the consistent task components that represent invariant responses to particular environmental cues or stimuli.
4. Practice on the consistent task components accounts for the eventual automation of the skill following extensive practice.

APPLICATION OF RESULTS

The consistency principle is most relevant to development of instructional strategies for complex skills.

- One instructional strategy would be to isolate specific consistent task elements of a skill and allow the learner to practice (part-task) such that the trainee receives numerous correct executions of the consistent tasks components of a specific skill.
- The above-summarized study supports this framework with the experimental demonstration that some rather complex tasks can be effectively trained in this manner.

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Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing I. Detection, search, attention. Psychological Review, 84, 1-66.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing II. Perceptual learning, automatic attending, and general theory. Psychological Review, 84, 127-190.

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REFERENCE SYNOPSIS

Schneider, W. (1985). Training high-performance skills: Fallacies and Guidelines. *Human Factors*, 27, (3), 285-300.

ABSTRACT: The authors make the point that all trainees do not reach the levels of proficiency desired in many systematic approaches to training, because many training programs are based upon false assumptions about human learning. This paper reviews and discusses six of the common training fallacies.

KEY TOPICS AND ISSUES:

1. Most learning studies are of too short a duration to draw broad generalizations about learning, and training effectiveness.
2. High-performance skills are characterized by three things:
 - The length of time to become competent and proficient at the task.
 - A typically high failure and non-completion rate for training.
 - There is a considerable performance difference between a novice and an expert.
3. Novices appear “overtaxed” and are easily distracted during performance, whereas the expert appears to perform smoothly and without effort, and is not easily distracted.
4. As one moves progressively, from novice to expert, the performance changes (in terms of competency exhibited and very likely in terms of the information processing and control tasks performed).
5. The expert makes decisions much more rapidly based upon experience, and without much “thinking” or deliberation.
6. Since the composition of the skill itself appears to change over time, then it would seem that the conditions of learning and the training strategy must change as well.
7. Most training programs do not take the changes in skill composition, or a learners progression from novice to expert into full consideration in arriving at the best instructional strategies for a learner’s progression in skill development.
8. Some of the more common fallacies of learning are as follows (pp. 287-89):
 - Fallacy 1: Practice makes perfect
 - Fallacy 2: Training of the total skill
 - Fallacy 3: Skill learning is intrinsically enjoyable
 - Fallacy 4: Train for accurate performance
 - Fallacy 5: Initial performance is a good predictor of trainee and training program success
 - Fallacy 6: Once learner has a conceptual understanding of the system, proficiency, will develop in the operational setting.
9. Training studies show support for such fallacies, as summarized below:

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a. Practice Makes Perfect

- Some studies show that practice on operational tasks does not necessarily improve performance. Sometimes no improvement is observed. It has been demonstrated that practice on consistent elements of a task does improve performance (i.e. consistent relationship between stimulus and response elements).

b. Training of the Total Skill

- Training in “real situations” or those with very high fidelity do not necessarily lead to the best training and performance. During performance of a real-world task, the learner (particularly the novice) is often overloaded and may not encode and retain needed information for learning and performance improvement. Often, a learner may improve learning by practicing parts of the total task and then practicing the whole task at a later training progression.
- Practice on consistent component tasks does improve component skills (p. 287).
- In many situations there is beneficial results (positive transfer) achieved with part-task training of key skill components.

c. Skill Learning is Intrinsically Enjoyable

- Failure rates in training can be improved with better incentives and improved performance feedback.

d. Train for Accurate Performance

- In most cases it is better to achieve acceptable accuracy while having the learner pay attention to critical tasks and important environmental cues.
- Over training may be desirable in cases that require a performer to work in a high workload operational environment.

e. Initial performance is a Good Predictor of Trainee and Training Effort Success

- Most initial performance is highly unstable and not a good indicator of ultimate performance of complex skills. The correlation between early performance scores and later performance is often very low.
- Many studies show that augmented feedback may *facilitate performance* during training but may actually *slow learning*.

f. Once Learner has Conceptual Understanding of the System, Proficiency will Develop in the Operational System

- Technical programs based substantially on only classroom teaching typically fail.
- There is no substitute for hands-on experience with the operational system. Learning a complex skill continues throughout an operator’s experience.

APPLICATION OF FINDINGS

- Trainers should focus on arranging practice on consistent task components.
- Complex tasks can be broken down into simpler components for part-task training with positive results.

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- Trainers should give considerable thought to sequencing of the tasks to be trained, and the kinds of performance feedback that may or may not be appropriate at various learning phases.

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Myers, G.L., & Fisk, A.D., (1987). Training consistent task components: Application of automatic and controlled processing theory to industrial task training. *Human Factors*, 29,(3), 255-268.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing: Detection, search, and attention. *Psychological Review*, 84, 1-66.

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REFERENCE SYNOPSIS

Smith, B.A. (1984). The optimum presentation of cognitive training during flight training program. In, Proceedings of the Human Factors Society—28th Annual Meeting.

ABSTRACT: Experiments were conducted while training flight maneuvers on a General Aviation Trainer for beginning aviation students. Instruction on cognitive components of the flight task was given at different times during the course of training. The study used three experimental treatment groups and one control group to study the effects of cognitive presentation methods. One treatment group received cognitive instruction in the traditional manner, given just prior to receiving any hands-on flight training. A second treatment group received the same cognitive instruction prior to commencing simulation trials but then got additional cognitive instruction throughout the entire training period. A third group did not receive any cognitive training before participating in simulation training, but did get cognitive instruction during simulation trials, and finally a fourth group served as a control in which no cognitive instruction was presented before or during simulation trials. The results of the study showed that subjects that only received cognitive instruction prior to commencing simulation trials performed better during acquisition and later transfer trials. Those that received cognitive instruction only during simulation trials performed significantly below the other experimental groups, and below the control group. *Results indicated that the presentation of cognitive instruction during simulation practice might in fact impair learning and transfer of performance on the maneuver studied.*

KEY TOPICS AND ISSUES:

The sequencing of instruction involving the presentation of either cognitive or perceptual components of a high-performance skill may have an important bearing on learning effectiveness.

- Cognitive components, regarding the structure of the task, instructions about correct task order, equipment capabilities and use, and instrument readings, etc. are best taught prior to commencing simulation trials.
- The best retention of perceptual components, regarding search patterns, cue distinctions, visual and kinesthetic feedback occurs when subjects are directly exposed to the flight environment and allowed to develop their own strategies during practice, without interference from external cognitive instruction.

APPLICATION OF FINDINGS

- When arranging simulation instruction, trainers should consider the optimum presentation of cognitive instruction to facilitate learning and transfer of training.
- It may be most beneficial to offer cognitive approaches early in training, and then shift to perceptual-motor aiding later in the training period.

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- Providing cognitive instruction, and “over-coaching” during hands-on equipment or simulation training may actually interfere with skilled-performance and with learning some complex skills.

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REFERENCE SYNOPSIS

Wightman, D.C., & Sistrunk, F. (1987). Part-task training strategies in simulated carrier landing final approach training. *Human Factors*, 29, (29), 245-254.

ABSTRACT: Two part-task-training strategies were tested during a carrier landing final approach task. The first strategy used segmentation (chaining) and the second strategy used task simplification (enhancement of the simulated aircraft's response to throttle adjustment). Performance on a video game was used to test motor-skills aptitude. The backward chaining approach (in which the last or terminal task is taught first) produced the best transfer to the criterion task compared to training on the criterion task itself. Aptitude treatment interactions were significant, indicating that the low-aptitude subjects benefited most from the backward chaining part-task-training method.

KEY TOPICS AND ISSUES

1. Carrier landing is a task very suitable to part-task training strategies using both segmentation and simplification techniques.
 - Segmentation is a procedure that partitions the criterion task into spatial or temporal parts. An example is backward chaining in which the final segment of a task like landing is practiced first and earlier task segments are progressively added during later training trials.
 - Simplification is a procedure in which a complex task is made easier by adjusting or controlling specific characteristics to simplify performance. For example, reducing control-display lag in a tracking system (Wightman and Lintern, 1985)
2. Results of this experiment corroborated earlier finding from Bailey, Hughes, and Jones (1980) which reported success using a backward chaining approach for training air-to-ground bomb attacks.
 - Subjects trained under the chaining approach outperformed those trained on the whole task during transfer tests. Fewer errors were made by the segmented training group so this treatment resulted in more training trials in which subjects were able to accurately perform their landing task.
 - Performance observed during acquisition and transfer also indicated that low-aptitude subjects benefited most from the segmented part-task-training strategy.
 - The use of controlled enhancements to aircraft responsiveness, as a part-task-training strategy was not found to be effective.

APPLICATION OF FINDINGS

1. Results reported showed that learning was more effective if subjects make fewer errors during training trials. Learners using the segmented approach made fewer recorded errors.

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2. The backward chaining approach also helps the learner focus on the correct performance of the terminal task (in this case the final landing task) without the “ambiguities resulting from the accumulation of errors on previous task segments.

RELATED REFERENCES

Wightman, D.C., & Lintern, G. (1985). Part-task training for tracking and manual control. *Human Factors, 27*, 267-283.

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ATTACHMENT B

PEDAGOGICAL KNOWLEDGE BASE SUMMARY

General Prescriptions:

- Provide students with tutorial information regarding the task structure and salient cues to pay attention to during task performance.
- Demonstrate correct performance to student, showing correct response sequence and timing.
- Reinforce attention to salient cues during practice sessions, and provide diagnostic feedback of performance results.
- As skill becomes more automated, provide less coaching and verbal support during task performance.
- It may be most beneficial to offer cognitive approaches to skill learning early in training, and then shift to perceptual-motor aiding later in the training period.
- Learner should be given a relevant organizational introduction to the task domain prior to engaging in practice trials, and then more emphasis should be placed on task specific information and coaching.
- Providing cognitive information and/or verbal feedback during practice, for trainees who have reached the level of skill automaticity, may actually interfere with learning.

Specific Prescriptions based on Literature Review

1. Allow learner to practice consistent task components over many training trials (Schneider, 1985).
2. Control task difficulty and information flow as to not overload short-term memory during early learning acquisition trials (Schneider, 1985).
3. Add variation to practice progressively, during later training phases, to represent anticipated inconsistencies in the operational environment (Schneider, 1985).
4. Present cognitive aspects of complex skills early in the training cycle, before substantial skill automation (Fitts, 1967; Smith, 1981).
5. Adjust task difficulty to minimize learner errors and to ensure exposure to perceptual cues associated with correct task performance (Wightman and Sistrunk, 1987).
6. Allow learner some time on simulation task that permits “free play” experimentation in order to permit the learner to develop individual strategies (Smith, 1981).
7. Complex tasks can be broken down into simpler components for part-task training with positive results (Schneider, 1985).
8. Arrange order of instruction such that knowledge and skill prerequisites are met before progressing to more difficult training sessions (Caro, 1973).
9. Feedback on good performance is as important as feedback on poor performance (Schimmel, 1988).
10. Clearly relate the learning objectives (task, conditions, and performance) to the operational environment (task demands, physical environment, information etc.).

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11. Allow for self-paced practice and provide knowledge of results feedback, especially during early training trials (Swezey & Llaneras, 1997).
12. Instructional designers should identify context (environmental) cues that are the most powerful in capturing attention and initiating correct or incorrect responses during later periods of training (Wightman and Sistrunk, 1987).
13. Learning is more effective if subjects make fewer errors during training trials.
14. Learners using the segmented approach made fewer recorded errors (Wightman and Sistrunk, 1987) compared to other part-task strategies.
15. The backward chaining part-task training strategy works because it helps the learner focus on the correct performance of the terminal task without the “ambiguities resulting from the accumulation of errors on previous task segments” (Wightman and Sistrunk, 1987).

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APPENDIX 2

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Hover Trainer Technology Review

July 2000

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Table of Contents

List Of Figures and Tables	4
Purpose	5
THE INTELLIGENT FLIGHT TRAINER (IFT).....	5
ADAPTIVE TRAINING SYSTEM (ATS) REQUIREMENTS.....	6
<i>Student Pilot (SP) Model Requirements</i>	6
<i>Instructor Pilot (IP) Model Requirements</i>	6
<i>Knowledge Acquisition Systems (KAS) Requirements</i>	7
<i>Required Interfaces between the ATS and the IFT</i>	7
Candidate Technologies	8
CONCEPTUAL GRAPH ANALYSIS	8
<i>Conceptual Graph Standard</i>	8
<i>Conceptual Graphs and ATS</i>	9
CASE BASED REASONING (CBR).....	9
MODELING AND SIMULATION	10
NEURAL NETWORKS AND GENETIC ALGORITHMS	10
Candidate Products	11
COMMONKADS METHODOLOGY	11
KATE.....	12
KNOT	13
SERVICESOFT 2001 (FORMERLY KNOWLEDGE BUILDER)	14
MICROSAINT	15
MIDAS	15
THE EASY REASONER.....	17
ATS Solution Architecture	18
HOVER TRAINING CHARACTERIZATION.....	18
<i>The Medical Analogy</i>	18
<i>Training as Treatment</i>	19
ATS COMPONENTS	19
<i>Voice Recognition</i>	20
<i>Student Monitor</i>	20
<i>Student Assessment</i>	21
<i>Training Assessment</i>	21
<i>Knowledge Base Editor</i>	23
SYSTEM PRODUCTION AND MAINTENANCE	23
CONCLUSIONS	24
BIBLIOGRAPHY	24

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List Of Figures and Tables

Figure 1: General Schematic of the IFT	5
Table 1: Sample Student Task	6
Table 2: ATS Metrics and Required IFT Inputs	7
Figure 2: Conceptual Graph Example	9
Figure 3: CommonKADS "eligibility assessment" task	12
Figure 4: KATE-CBR Interface	13
Figure 5: ServiceSoft 2001 Application Architecture	14
Figure 6: MicroSaint Modeling and Simulation Interface	15
Figure 7: User View of MIDAS	16
Figure 8. MIDAS Domain Model Objects and Relationships	16
Figure 9: Rule-based Inference Engines from The Haley Enterprise	17
Figure 10: CBReete++ and The Easy Reasoner from Haley	17
Figure 11: ATS Component Architecture	20
Figure 12: Encapsulating IFT for integration with ATS	22

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Hover Trainer Technology Review

Purpose

The US Army is interested in reducing the cost of training students to hover a helicopter. In pursuit of this goal, the Office of the Secretary of Defense (OSD) is sponsoring the Small Business Innovative Research (SBIR) contract OSD99-04 to enhance the Army Research Institutes' (ARI) Intelligent Flight Trainer (IFT). The desired enhancement would automatically adapt the IFT to facilitate student learning in the absence of an instructor.

This report summarizes an effort to identify and determine the feasibility of a technical approach to implementing the IFT training enhancement. Following a brief description of the IFT and the general solution architecture, several commercial software products are reviewed as candidates for inclusion in the final system implementation. The report concludes with the recommended system architecture, knowledge acquisition approach, and required software components.

The Intelligent Flight Trainer (IFT)

The IFT is currently described as an automated and adaptive helicopter instructor pilot providing verbal instruction to novice pilots. It also has the ability to augment control inputs until the student is able to accomplish a given maneuver unaided. While this description seems to satisfy the requirements for an automated hover trainer, it does not adequately adapt the instruction provided to the experience level of the student pilot. The IFT consists of several cooperating PC-based computer systems. The main system is a Dell 610 Dual Processor machine running LINUX that serves as the central controller. It hosts the software responsible for the helicopter flight model, instrument panel graphics, and adaptive instructor functions. Figure 1 presents a schematic of the IFT.

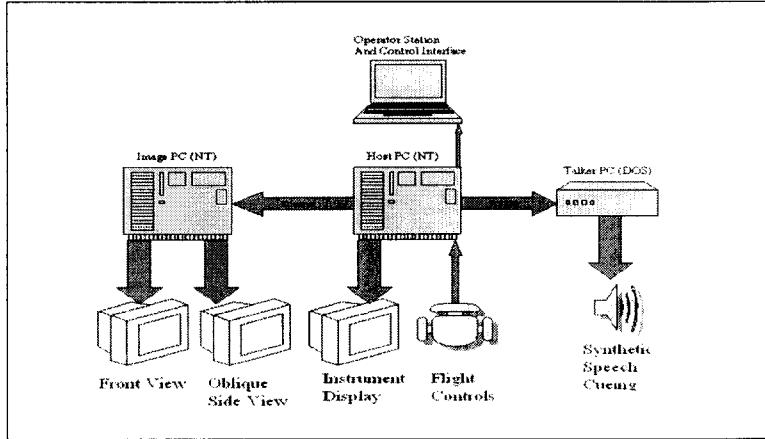


Figure 1: General Schematic of the IFT

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A second Dual Processor system running Windows NT is used to generate the two "out-the-window" views displayed to the student. The graphics are generated on accelerated displays using the OpenGVS simulation toolkit. The IFT also maintains the ability to drive an ESIG 3000 Image Generator. A third machine running MS-DOS is used to generate synthesized speech instructions. In addition to the two "out-the-window" views, the main system generates two other screens of information. The first screen generated is an operator station display that provides menu control over the system and access to flight parameters. The second screen is positioned in front of the pilot and presents flight instrumentation using the TIGERS software package.

Adaptive Training System (ATS) Requirements

The initial proposal for SBIR OSD99-04 proposed to build an Adaptive Training System (ATS) that is comprised of several components. The following identifies the high level components that make up the general ATS:

1. Model of the Student Pilot (SP),
2. Model of the Instructor Pilot (IP),
3. Knowledge Acquisition Systems (KAS), and
4. Interfaces between the ATS and the IFT.

The SP model encapsulates all knowledge and processing required in estimating the student's skill state and task understanding. The IP model encapsulates the reasoning systems required to diagnose student deficiencies and recommend training remedies. The Knowledge Acquisition Systems (KAS) facilitate the construction and maintenance of the SP and IP models. Finally, appropriate connections between the ATS system and the IFT must be established.

Student Pilot (SP) Model Requirements

The SP model as described here provides a standalone evaluation of a student helicopter pilot in the IFT. The evaluation should employ current performance data and the student's history with the IFT. Two primary areas of evaluation should be modeled: task understanding and skill state. Skill state describes a level of perceptual-motor performance against a given control task in the IFT under specific conditions. To evaluate a student's skill state, the SP model must represent goal performance for the given task and determine the skill ranking using measures obtained from the IFT. The following is an example of a task and potential skill state metrics.

Task	Maintain Lateral Position
Criteria	+/- 5 feet from designated spot
Conditions	.5 knot crosswind, gusting to 15 knots
Metrics	"Average error", "maximum error", "number of deviations", "frequency of deviations", and "duration of deviations".

Table 1: Sample Student Task

Quantifying a student's "understanding" of a task is more difficult than determining skill state. In simple cases, inferior performance on a specific task may clearly indicate a lack of "understanding" with regard to what is required to accomplish the task. However, composite tasks that have several objectives may lead to contrary indications of "understanding".

Instructor Pilot (IP) Model Requirements

An instructor pilot begins with a student and a training goal. The instructor assesses the student's skill level with regard to the training goal and develops a training plan. Armed with a training plan, the instructor engages the student in a series of activities intended to provide an efficient context for acquiring the required skill level.

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The training engagements provide additional opportunities for assessing the student's skill level and identifying any difficulties in accomplishing specific tasks. As difficulties are encountered, the instructor must attempt to diagnose the cause of the student's trouble. Once the problem is diagnosed, the training plan can be altered to address the newly discovered information needs of the student.

Timely adaptation of the training plan to the needs of the student is critical in providing efficient instruction. Frustrations over not being able to perform a task can be as irritating as working on skills that have already been mastered. Frustration might indicate a requirement for remedial training and suggest a postponement of the currently planned "practice". On the other hand, perfect performance may suggest an acceleration of the training plan schedule.

Knowledge Acquisition Systems (KAS) Requirements

The first rule in building an Expert System is that there must be at least one expert available during the construction of the system. In practice, this is perhaps the most frequently broken rule in Expert System development. The Subject Matter Expert (SME) in a field is often in high demand and not always available when needed.

To stretch the SME budget a little farther, several experts are generally consulted over the period of a systems development to capture specializations. Many experts contributing knowledge to a system over a longer time drives the need for an interchangeable knowledge structure. The successful approach to developing and maintaining the Adaptive Training System (ATS) should include one or more Knowledge Acquisition Systems to help maintain and formalize acquired knowledge.

The KAS should support developers and experts in the accomplishing the following tasks related to knowledge-based system development:

- Select appropriate representations for knowledge,
- Organize knowledge and manage changes to the knowledge base,
- Explain the purpose for specific knowledge structures,
- Identify relationships between cooperating knowledge structures.

The tools selected to implement knowledge structures should address the following implementation and maintenance concerns:

- Representation portability between components,
- Heterogeneous interoperability,
- Automated regression testing,
- Scalable repository management.

Required Interfaces between the ATS and the IFT

In order for the ATS to drive the IFT, control aspects within the IFT must be exposed to ATS. In addition some data items maintained by the IFT must be made available to the ATS. With the exception of environmental perturbations, all of the required data from the IFT is currently output to a file every 60 frames. This output mechanism can be altered to provide data to the ATS. The following table identifies inputs needed from the IFT in order to compute a given metric on the ATS.

ATS Metric	Required Input from IFT
Control Position & Displacement Frequency	Time stamped axis value and flight model calibration tables.
Vehicle Degrees of Freedom	Time stamped position, velocity, acceleration, orientation, angular velocity, and angular acceleration vectors for the vehicle
Flight Handling Qualities Augmentation	Alterations to the base flight model. Sensitivity damping, axis reduction and any other FHQ Augmentation.
Environmental Perturbations	Time stamped wind velocity and direction. Visibility attenuation and scale.

Table 2: ATS Metrics and Required IFT Inputs

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In order to reuse all existing simulation capabilities encapsulated within the IFT, control aspects that are currently within the IFT must be exposed for use by ATS. The following list identifies control aspects of the IFT that are needed by the ATS :

1. Flow control: The remote initiation and termination of the IFT.
2. Remote flight control: The ability to bypass the IFT flight control augmentation and pass ATS flight control values to the flight model.
3. Remote voice control: The ability to bypass the IFT verbal instructions and pass the ATS verbal instructions to the voice synthesizer.
4. Remote environmental control: The ability to pass ATS commanded wind and visibility control to the IFT flight model and graphics systems.

Candidate Technologies

The technologies identified in the section were evaluated for use in implementing the ATS. In general, these technologies identify knowledge representations for solving specific types of problems. Where appropriate, ATS requirements are mapped to the considered technology to direct candidate product reviews.

Conceptual Graph Analysis

Conceptual graphs (CGs) are a system of logic based on the existential graphs of Charles Sanders Peirce and the semantic networks of artificial intelligence. Meaning is expressed in a logically precise, humanly readable, and computationally tractable form. Direct mappings to language and the common Knowledge Interchange Formats (KIF) make CG's useful in developing and maintaining knowledge-based systems.

Conceptual Graph Standard

Figure 2 presents a graphical representation of the concept "Tom believes that Mary wants to marry a sailor". This concept demonstrates context by depicting the nested concepts of Proposition and Situation. It also demonstrates a co reference link between Mary and her surrogate instantiation in the nested concept Situation.

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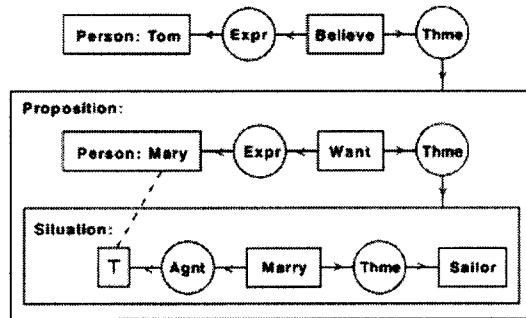


Figure 2: Conceptual Graph Example

The Conceptual Graph Interchange Format (CGIF) for Figure 4 is:

```

/Person: *x1 'Tom' /Believe *x2] (Expr ?x2 ?x1)
(Thme ?x2 /Proposition:
  /Person: *x3 'Mary' /Want *x4] (Expr ?x4 ?x3)
  (Thme ?x4 /Situation:
    /Marry *x5] (Agnt ?x5 ?x3) (Thme ?x5 [Sailor]) )) ),
  
```

and the Knowledge Interchange Format (KIF) is :

```

(exists ((?x1 person) (?x2 believe))
  (and (expr ?x2 ?x1)
    (thme ?x2
      (exists ((?x3 person) (?x4 want) (?x8 situation))
        (and (name ?x3 'Mary) (expr ?x4 ?x3) (thme ?x4 ?x8)
          (dscr ?x8 (exists ((?x5 marry) (?x6 sailor))
            (and (Agnt ?x5 ?x3) (Thme ?x5 ?x6)))))))) )
  
```

Conceptual Graphs and ATS

The ability to create and manage conceptual relations in a variety of formats provides a robust basis for knowledge acquisition and knowledge structure explanation. Tool selection should provide for a convenient flow of representations between human and machine-readable forms. The Conceptual Graph Structure provides a standard representation for connecting systems with a variety of internal knowledge representation structures.

Assuming that ATS will use several products to develop and maintain the system, CG's could serve as a representation for knowledge acquisition products generated during interviews with helicopter instructors. The CG tool should support the real-time interrogation of existing knowledge structures in addition to generating new structures. As instructors offer expertise, the knowledge engineer needs the capability to identify redundant, conflicting, or new concepts. If conflicting concepts are discovered, this current knowledge acquisition session may represent the only opportunity to unravel the source of the conflict.

Over time, instructors encounter students with a wide variety of training difficulties. Expert instructors anticipate these difficulties based on their experience with other students of similar skill level. The training of an instructor involves building up a network of discrimination concepts that relate the student's skill level to the types of performance problems that the student may have with a given task.

Case Based Reasoning (CBR)

Case-Based Reasoning (CBR) is a software technology that supports decision-making and problem resolution by leveraging prior experience. In CBR, a particular experience is represented in a database by one or more cases. Any number of attributes describing the specific information detailing a case is remembered and used to identify this case as relevant in solving some future problem.

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The Reasoning part of CBR involves the representation of an "understanding" of the problem being solved. This is required to allow the CBR system to adapt prior experiences to the current problem context. In order to understand a prior experience, it is remembered with associative or conceptual relations. These relations provide a means for the Reasoning part of the CBR system to retrieve relevant cases.

Once relevant cases are retrieved, an understanding of the differences between the prior experience and the current problem are used to select the best-fit cases. A solution that worked in the past is then adapted to generate a new solution for the current case. If the retrieved cases are irrelevant, a new case is added once the new problem has been solved by traditional means.

Benefits from Using Case-Based Technologies include:

- Finding solutions to complex problems more quickly,
- Discovering decision knowledge hidden in data using induction,
- Transferring experience from skilled specialists to novices,
- Building a corporate memory by sharing individual experience, and
- Demonstrating expertise in domains that are poorly understood because CBR does not need to know why a solution worked in the past.

The automatic generation of decision trees from a database of stored cases is called induction. Given a set of cases with problem specific relevance measures and existing solutions, a decision tree can be developed that will classify the existing case-base along some decision concept. The generated decision tree can then be used to classify and suggest solutions for completely new problems without consulting the case-base.

It is important to realize, however, that induced decision trees treat all new cases as if they "match" one of the prior cases. Since the decision tree was synthesized from the case-base, decision trees must be re-generated when important changes to the case-base are stored.

In addition to using the generated decision tree to "speed up" ATS response to new cases, the induced decision tree could be employed during training concept discovery. The decision tree produced from a case-based rule induction results in a generalized representation of the underlying specific instances. This automated generalization process could result in an efficient validation and verification mechanism for ATS knowledge engineers.

Modeling and Simulation

Modeling and simulation (M&S) is a general category of technology that attempts to utilize known relationships to predict the behavior of a system. Designers employ simulations of proposed systems to estimate overall differences between design alternatives. Human Factors researchers use M&S to estimate the affects of design alternatives on human operators. Finally, the simulations can be used to train the human operators, as is the case with the IFT.

While the ATS is specifically designed to control a helicopter hover training simulator, it could itself be viewed as a training simulator for helicopter instructors. An instructor could observe the behavior of the system and request explanations regarding its decision-making.

The type of M&S considered here supports knowledge engineering activities focused on the development of the ATS. The M&S function that would be most useful in knowledge base construction and concept discovery is a model of the student helicopter pilot. A collection of models ranging from novice to expert would provide test cases to exercise all aspects of the completed ATS.

Neural Networks and Genetic Algorithms

Neural Networks are collections of nodes that are analogous to neurons in the brain. The nodes are interconnected in a network that has the potential to identify patterns in data. Each of the nodes are processing elements that represent weighting factors for each of the interconnections. When training sets are combined with a learning strategy for adjusting the weighting factors, networks can be developed that can learn almost any function regardless of noise in the data or function complexity.

Neural Network (NN) node densities and training sets are the keys to developing an accurate solution. High densities for simple problems result in networks that learn about the noise in the training sets. Low densities for complex problems result in networks that never quite get "smart" enough. In addition, at least three training sets must be available: the training set, the test set, and the validation set. The test set is used during training to monitor learning performance and the validation set is used to determine the final model performance.

For a NN to perform the ATS hover instruction task, the network would need to be extremely dense due to the large number of input and output nodes. Input nodes "sense" information from the environment and output nodes "react" with appropriate solutions. This dense network would need a large number of training data sets to "exercise" all portions of the network.

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Instead of performing the entire ATS instruction task with a single network, perhaps individual networks could be devised that worked on single aspects of the instruction task. For example, a single network might classify a student's skill state as acceptable or not. Others might classify certain vehicle motions as "out of bounds" and issue a warning.

The main difficulty with Neural Networks (NN's) is in trying to explain their behavior. This in turn makes the network hard to maintain. All you can really do is add your new data to the training set(s) and retrain the network. This incremental increase in training set complexity may eventually overwhelm the existing architecture, forcing an adjustment to the node densities.

Genetic Algorithms (GA's) are algorithms that by their nature evolve into solution providers. Populations of "infant" algorithms are released into a problem environment and rated for fitness. New populations are constructed by crossing over the parents to create new offspring and then mutating them using some probabilities. These new populations are released back into the problem environment and the process continues until an end condition is satisfied.

If you were thinking that it might take a while to train a neural network in a complex environment, imagine the time required to evolve a solution to providing helicopter instruction to a human subject. As before, a simplification of the problem environment may reduce the complexity, but selecting appropriate pieces of the problem would be at best difficult. Other issues include selecting the genetic encoding scheme, specifying the crossover function, and the mutation function.

For ATS, both NN's and GA's require significantly larger supplies of test data than other approaches to implementing expertise. Neither is able to supply a human understandable explanation of how it arrives at a decision. And finally, there is significant risk as to whether the problem is solvable given the selected node densities, training sets, fitness measures, crossover functions and mutation approaches. For these reasons, NN and GA products were not evaluated as candidates for employment in developing the ATS.

Candidate Products

CommonKADS Methodology

CommonKADS does not claim to be a full knowledge-management methodology, but is in practice used successfully as a powerful tool to support knowledge management. The analysis framework provides an extensive method for describing business processes in which knowledge-intensive tasks are carried out. It is not offered specifically as a tool, but is instead a methodology that can be employed using standard organizational toolsets.

With a clear focus on knowledge analysis, CommonKADS provides tool methods required to analyze knowledge-intensive tasks at different grain-size levels. The analyst is supported in the modeling process by "templates", which constitute predefined reusable and proven knowledge models. The templates enable a top-down approach and provide handles for quality control and feasibility.

Knowledge analysis is aimed at studying knowledge-intensive tasks at a conceptual level. The analysis results in a description of the information and knowledge structures and functions involved in the task. The knowledge model plays a key role in both knowledge management work and in consecutive system-development activities. Figure 3 presents a sample template for the "assessment" task used to decide if a prospective homebuyer should be eligible to buy a particular residence.

The representation techniques employed by CommonKADS are similar to mainstream object-oriented design paradigms. In fact, the diagram in Figure 3 is expressed using the Universal Modeling Language (UML), a standard Object-Oriented modeling notation.

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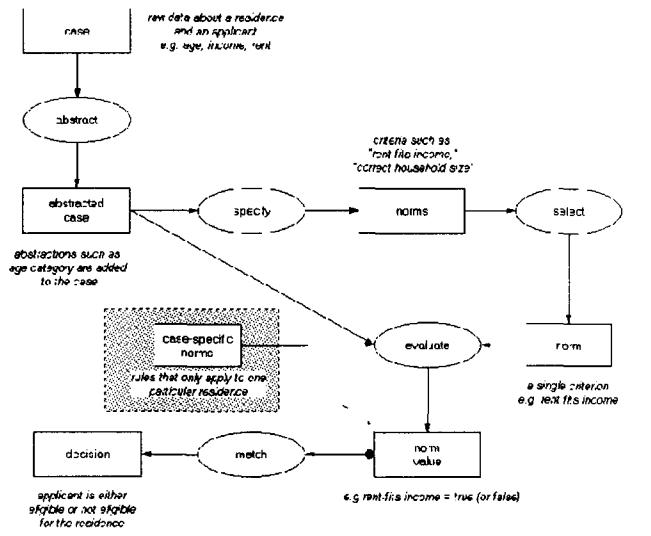


Figure 3: CommonKADS "eligibility assessment" task

While this type of detailed modeling is desired in establishing requirements and documenting relationships between components, it does not specifically provide management software tools. CommonKADS specifically addresses the following:

1. Analyzing the Existing Infrastructure
2. Aligning Knowledge Management and Business Strategy
3. Designing the Knowledge Management Infrastructure
4. Auditing Existing Knowledge Assets and Systems
5. Designing the Knowledge Management Team
6. Creating the Knowledge Management Blueprint
7. Developing the Knowledge Management System
8. Deploying and Using the Results-driven Incremental Methodology
9. Managing Change, Culture and Reward Structures
10. Evaluating Performance, Measuring ROI, and Incremental refinement.

For ATS, the main problem is to develop a system that adapts its own behavior. In CommonKADS, the ATS developer can model existing knowledge constructs, but is not directly supported in the production of the implementation vehicle. For projects that need to include considerations about knowledge-based processing into a standard Object-Oriented (OO) Programming cycle, CommonKADS would be useful. It would provide a good OO Analysis and Design platform from which to launch an implementation phase.

For ATS, the implementation phase represents a primary source for knowledge acquisition activities. Instructors that are interviewed for validation of training sequences will be queried about their reactions to large numbers of cases. Synthesizing their responses in the form of conceptual discriminators will be a challenge to knowledge engineers. We need a suite of tools that provide for a smooth flow of conceptual discovery from the implementation environments collection of experiences and not just a good OO design and analysis methodology. However, the lifecycle management of the ATS as a whole must consider all of the aspects addressed in the CommonKADS methodology.

KATE

The KATE suite of software, developed by AcknoSoft International (France), is a collection of 4 tools for developing CBR applications: KATE-editor, KATE-Data Mining, KATE-CBR and KATE-runtime. Optional components are available for specific help desk application, service management, and decision support over the Internet. A KATE Dynamic Link Library (DLL) is available to facilitate integration with other applications.

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KATE-Data Mining claims to be the fastest rule induction algorithm available for discovering decision knowledge in a case-base. KATE-induction includes a graphical browser of the decision tree to navigate through the learned knowledge and retrieve cases at any node. It also provides for the treatment of unknown values and the integration of background knowledge.

KATE-CBR contains two modules: the nearest neighbor module and the dynamic induction module. The nearest neighbor module is used to compare the current problem with ones that have already been solved, retrieve the most similar cases, and adapt their known solutions. The dynamic induction module enables discovery of the most discriminating questions and retrieves relevant cases efficiently. Figure 4 presents a sample interface for the CBR tool.

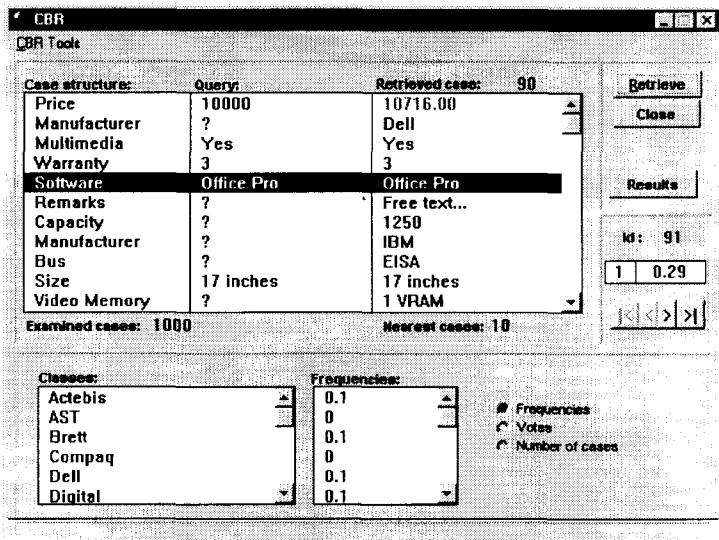


Figure 4: KATE-CBR Interface

KATE-Editor provides for the object-based modeling of cases. It uses the object model to generate interactive questionnaires for editing the case library. The editor is implemented as a set of C DLL's to allow extension to user interfaces. KATE-runtime provides a distributable engine for fielding developed solutions.

The CASSIOPEE system, awarded the 1995 European prize for innovative software applications, was developed using KATE. The system performs diagnosis of the CFM 56-3 engines on the BOEING 737. It contains over 23,000 cases of which 70% are used for CBR diagnosis.

The retail price of KATE is \$15,000 and it is available for the Windows 3.1, 95, and NT 3.51 and 4.0. KATE WebServer and the KATE libraries are also available on Sun Solaris and soon for Linux on all machines.

KNOT

The Knowledge Network Organizing Tool (KNOT) is built around the Pathfinder network (Pfnet) generation algorithm. Pathfinder algorithms take estimates of the proximities between pairs of items as input and define a network representation of the items. The network consists of the items as nodes and a set of links connecting pairs of the nodes. The set of links is determined by patterns of proximities in the data and parameters of Pathfinder algorithms.

This type of network analysis is typically employed in the construction of neural networks. Given a set of training data, users manipulate KNOT functions to analyze relationships between nodes. Concept discovery, however, could be viewed as a similar search for the nodes in a graph given some known relationships. The following functions are provided in the KNOT system:

- Collect pairwise rating data.
- Make a nonsymmetric matrix symmetric.
- Average multiple data files.
- Compute a coherence measure on proximity data.

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- Correlate pairs of proximity data sets.
- Generate Pathfinder networks from proximities.
- Compute distances in PFnets.
- Compute the similarity of two PFnets.
- Compute node positions for a display of a PFnet.
- Handle multiple data files.
- Display a PFnet.
- Move nodes to new positions (links follow).
- Print a PFnet.
- Create and erase nodes or links.
- Edit node labels (multiple line labels).
- Display directed links.
- Handle directed links in a display.

The KNOT system is oriented around producing pictures of the solutions, but representations of networks and other information are only available in the form of text files. KNOT may be useful to knowledge engineers as an offline analysis tool, but does not provide any directly useable connections to other technologies. Once ATS has represented a first-cut at conceptual relationships in the training data, KNOT could assist in validating those relationships or perhaps discover "better" relationships.

ServiceSoft 2001 (formerly Knowledge Builder)

ServiceSoft 2001 is a Case-based reasoning (CBR) tool. It provides turnkey CBR solutions to service related problem solving. It is a classical CBR tool focusing exclusively on providing support for the retrieval, reuse, revision, and retention of cases. Figure 5 presents the companies' product in the context of integrated platforms and applications.

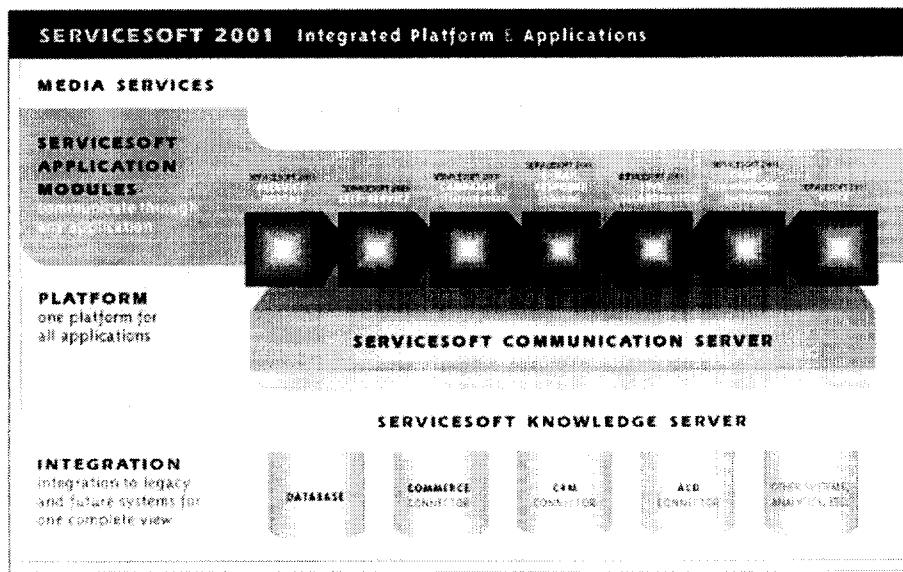


Figure 5: ServiceSoft 2001 Application Architecture

The old Knowledge Builder functionality is still behind the scenes helping knowledge engineers implement the initial CBR implementation. The Knowledge Builder product is no longer sold independently, but is incorporated into all Servicesoft 2001 products. For ATS, we would have to model the behavior as a service application along the lines of one of the internet-based ServiceSoft products.

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While a detailed investigation of the integration potential of any of these products was not possible, ServiceSoft 2001 does not explicitly provide links to other types of reasoning. The requirements for ATS to integrate several reasoning models may preclude its use as the exclusive tool for implementing training expertise in ATS.

MicroSaint

MicroSaint is a discrete-event modeling and simulation tool. It provides simple mechanisms for constructing event-driven simulations with stochastic perturbations. Simulations are constructed from task networks in which each task is given some behavior. The behavior can accomplish some business function or set some variables.

Users can define variables, queues, and functions that are manipulated or used by the tasks. Tasks are assigned mean and standard deviation times that allow the simulation to randomly assign task durations. Several visual representations are provided that provide displays of task progress. Figure 6 presents a view of the task network for one of the demonstration simulations.

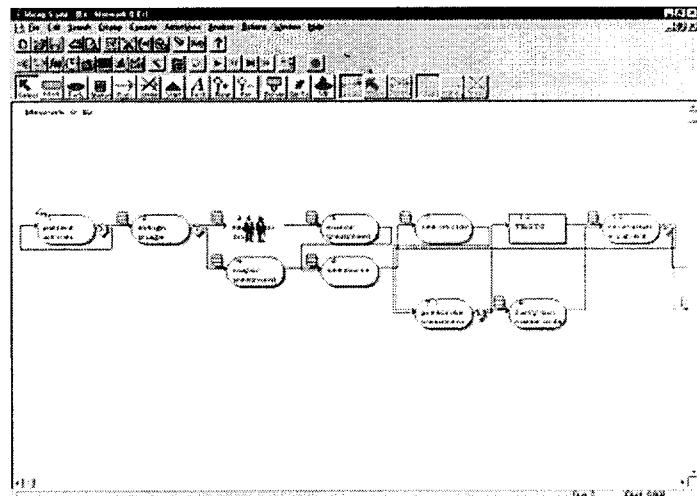


Figure 6: MicroSaint Modeling and Simulation Interface

In addition to the task view above, the action view provides an animation for simulations that must consider space issues in the simulation. Dynamic task queues and variable displays provide for a lively simulation interface.

The system is primarily used to demonstrate and test workflow. Objects, tasks, variables, functions, and queues combine to demonstrate bottlenecks and underutilizations. Simply modifying the deviation of the task duration can clearly identify brittle areas of an organizational structure.

For ATS, MicroSaint might be used to model the effect of a student reacting too slowly to a vehicle motion. Perhaps it could even model the effect of an instructor reacting to inadequate student performance. Unfortunately, the existing task structure could not represent the flight model of the vehicle and the simulation would not provide adequate demonstrate a true failure in the control of a hovering helicopter.

However, MicroSaint recently added COM services to its interface so that it can connect with other simulations. If ATS were to provide a COM-based flight model for use by MicroSaint, then the simulations could possibly identify reaction time limits for instructional cues. One of the most challenging aspects of providing helicopter instruction is to give the student as much time as possible to identify and recover from an unwanted flight regime.

MicroSaint currently sells for \$8,995.

MIDAS

The U.S. Army, NASA, and Sterling Software Inc. have developed MIDAS to aid in the design of advanced aircraft cockpits. MIDAS, the Man-machine Integration Design and Analysis System, combines graphical equipment prototyping, dynamic simulations, and human performance modeling to aid in the design of crew stations and their associated operating procedures.

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A system of cooperating agents, MIDAS integrates editors and analysis tools written in C, C++, and LISP. An interactive mode supports layout of crew stations, assessments of visibility and legibility, examination of anthropometric characteristics, and analyses of cockpit topology and configuration. A simulation mode provides facilities to estimate a human operators employment of cockpit equipment to accomplish mission procedures in an integrated fashion. Figure 7 presents a user's view of MIDAS.

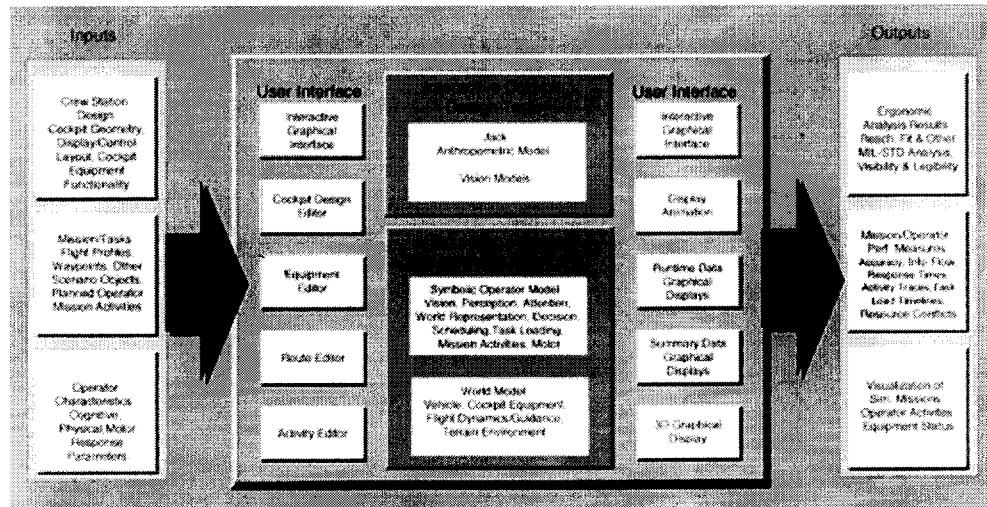


Figure 7: User View of MIDAS

Execution of the simulation mode results in activity traces, task load timelines, information requirements, and mission performance measures. A graphics system provides simulation visualization and a results analysis system supports examination of simulation data. An interface that allows users to construct target domain models is also provided. Figure 8 presents an example domain model object and relation diagram.

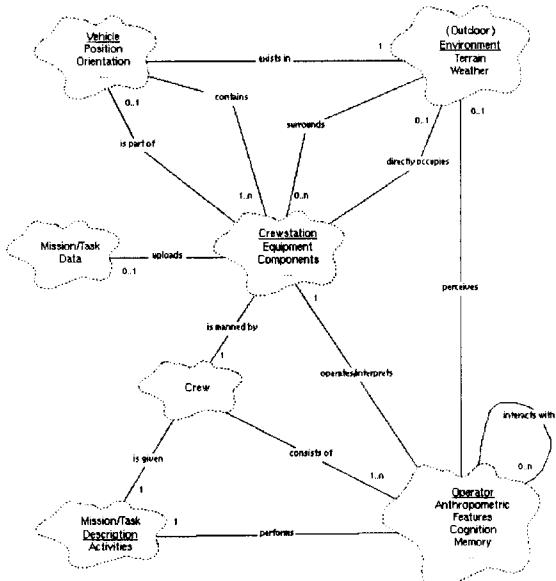


Figure 8. MIDAS Domain Model Objects and Relationships

Unlike MicroSaint, MIDAS has the potential of integrating vehicle performance characteristics into the model of the simulation. Investigations into how long an instructor could wait before intervening with verbal cues or control augmentation could be carried out across an array of different student models. The determination and representation of this type of temporal reasoning within ATS presents a challenging task.

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Instructors probably do not have fixed times that they give students to figure out control problems. As a result, empirical observation and simulation may be the only available acquisition methods.

The Easy Reasoner

The Easy Reasoner (TER) suite of products, available from The Haley Enterprise, Inc., provides a unique integration of several knowledge-based processing paradigms. While most of the reviewed products focus on a single technology, TER provides an integration path between a rule-based inference engine and a Case Based Reasoning (CBR) toolset in a package that provides several common interface options. Figure 9 presents the integration options available with the Eclipse inference mechanism that is bundled with the ER product suite.

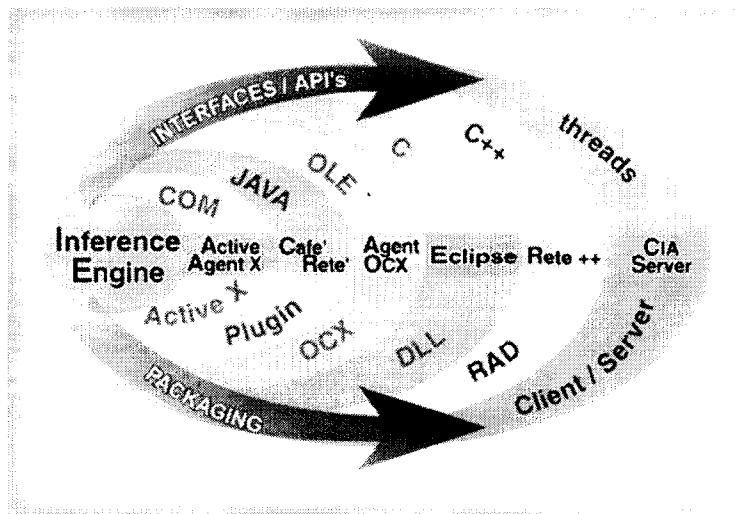


Figure 9: Rule-based Inference Engines from The Haley Enterprise

The rule-based inference mechanism in Eclipse is based on the Rete algorithm. Rete was proven to be the most efficient production rule execution process in the late 70's. Treat was subsequently proven to be faster for parallel execution, but the difference was slight. Derived from the original work done on OPS5, ART, and CLIPS, Eclipse provides backward and forward chaining, truth maintenance, taxonomic representations, and inheritance. Rete++ provides a C++ code generating encapsulation of Eclipse.

TER also provides a rule induction capability for synthesizing decision trees from relational databases called ClassIE. It automatically handles missing data during induction and retrieval using probabilities. Interactive selection of columns for induction and pruning of the resulting decision trees provide users with the ability to make "human sense" of the induced tree. Figure 10 shows the relationship of the several products with TER.

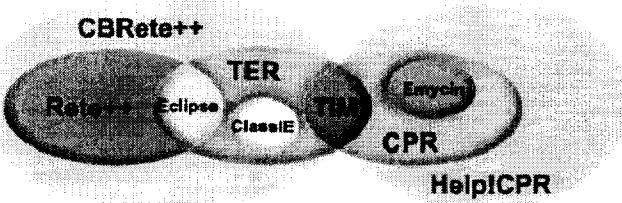


Figure 10: CBRete++ and The Easy Reasoner from Haley

Case-Based Reasoning (CBR) functions are provided in another product CBRete++. As you can see in Figure 10, this tool encapsulates the Rete++ and TER products providing a unified environment in which to field solutions that integrate CBR and rule-based reasoning. Using direct access to the induced decision tree used for the indexed retrieval of cases, applications can implement interfaces to allow end-users to retrieve

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classified cases. The API that provides access to the tree also allows the application to construct a case programmatically or by form filling and traverse the decision tree based on the newly constructed case.

Finally, Haley offers yet another integrated product to support problem diagnosis. Case-based Problem Resolution (CPR) employs case-based retrieval with rule-based diagnosis to lead users to problem resolutions. Case-based retrieval alone does not assist in identifying a problem solution unless the problem case "exactly" matches a stored case. Instead, decision procedures are assembled using independent rules that identify: positive or negative evidence regarding a symptom, the logical role of some information, or the evidentiary role of some information.

CBRete++ is priced at \$4000 and the CPR toolkit is \$1999. Runtime licenses are required for the distribution of applications. For implementing ATS, this package provides the most complete coverage of knowledge representations and access to underlying knowledge structures of all the reviewed technologies. The only shortcoming is the ability to import and export standard knowledge structure formats like CGIF or KIF. However, with access to the internal rule definition features of Rete++, the construction of an interchange mechanism should be simple.

ATS Solution Architecture

This section attempts to combine existing technology and available products into a plan for developing the Adaptive Training System (ATS). The helicopter hover training problem is first characterized and then knowledge structures organized to provide a map to the solution of building the ATS. Finally, suggestions are offered with respect to managing the development and maintenance of the ATS.

Hover Training Characterization

The problem of training a student to hover a helicopter is analogous to the problem of treating an illness. If you consider the student pilot lack of skill in performing a task as an illness, then the role of the instructor is the same as a doctor. For both serious illnesses and aircraft manipulation, an inability to recognize and respond to situations can present similar outcomes. The following section presents the medical analogy. As you read the section, reflect on how each of the concepts presented would operate in the helicopter training environment.

The Medical Analogy

Most medical professionals routinely perform a series of tasks that attempt to improve the quality of health in the patient. The routine begins by collecting symptoms that describe the chief complaint of the patient. For unconscious patients, collecting symptoms is guided by a standard protocol that assumes the worse case until proven otherwise.

Next, the clinician attempts to diagnose the cause of the problem by correlating symptoms and patient history with known disease conditions. Once a plausible diagnosis is reached, tests may be ordered to confirm the diagnosis. If no plausible diagnosis is reached, tests may be ordered to begin the systematic process of "ruling out" the most probable disease conditions.

Armed with either a confirmed or suspected diagnosis, the clinician again correlates symptoms and patient history together with the diagnosis in an attempt to identify an appropriate treatment for the illness. In some cases, the illness itself is not treatable and only the symptoms can be addressed. Standard treatment recommendation guidelines are often available to clinicians for addressing specific symptoms and disease categories.

During treatment administration, the clinician collects metrics that indicate the treatment effectiveness. Treatment side effects and allergies can produce a worse illness than the one being treated, so a close monitoring of the outcome of treatment regime is required. If the patient cannot tolerate the treatment, then it is discontinued and the search for an alternative treatment begins. If the patient tolerates the treatment and shows minor improvements, an increase in the treatment frequency or magnitude may be warranted.

The clinician continues this potentially endless cycle of activities between diagnostic evaluation, treatment administration, and outcomes measurement until the patient is healed, killed, or simply doesn't show up any more. Since clinicians generally treat more than one patient, outcome measures can be obtained on aggregate patient populations. These aggregate outcomes measures can then be used to estimate the overall effectiveness of a clinician's diagnosis-treatment protocol.

Finally, the medical associations collect statistics on clinician performance and identify areas in which successful protocols need to be made available to clinicians in order to increase outcome success rates. The form of these clinical guidelines is usually a paper protocol, but many protocols are now being fielded as interactive knowledge-based systems.

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Training as Treatment

With respect to flying a helicopter, the inability to maintain a stable hover can be thought of as a serious illness that needs treatment. In this case, the instructor serves as the clinician did in the medical analogy. Instead of a disease that has a physiological basis, this disease is characterized by a lack of understanding or skill. The instructors' treatments take the form of practice sessions to refine perceptual-motor skills and explanations to implant or repair a student's conceptual model regarding required tasks.

While a student may identify a symptom, often the student doesn't even know their sick. The instructor continually monitors student behaviors looking for symptoms that indicate some underlying problem. A wandering rotor RPM, airspeed, and/or altitude, are all good symptomatic indicators of an underlying deficiency in flying skills. A student that is inattentive to the above indicators may have a successful flight (walk away from landing), but is clearly in need of treatment.

In the same way that clinicians employ patient histories, instructors establish expectations of performance by looking at the students' flight record. If the instructor has flown with the student before, then more detailed information may be available than can be found in the "official" flight record. Typically a logbook identifies maneuvers that were executed (or attempted), but they do not provide performance details regarding the quality of the maneuvers. The instructors experience with the student may indicate a tendency to over react or over control.

The instructor combines the student's history with a current skill assessment to select the part of the "disease" process to attack next. In the same way that clinicians with limited experience use treatment guidelines, instructors employ training curricula when there is no clear diagnosis of the next illness to address. A training curriculum is really a sequence of treatment recommendations to be used on all students. Some instructors simply push students through these treatment recommendations without deviation.

Expert instructors, however, are able to identify specific deficiencies in student performance and customize a training curriculum that is more efficient than the "one size fits all" training plan. The instructor is not just attempting to minimize the time spent acquiring the skill, but is also trying to increase the safety of the training process by minimizing the time spent in a skill deficient state. Whether customized or canned, the instructor proceeds by administering treatment in the form of a training session.

In ATS, training sessions are offered in the form of either a simulated flight or a classroom session. Simulated flight training sessions place the student in the IFT with a specific set of training goals. Tasks are focused on vehicle maneuvering and control manipulation. Classroom sessions place the student in front of a computer interface with a focus on establishing conceptual structures needed to understand upcoming flight training tasks. While the student's specific interface to ATS is different in the two cases, each "treatment" involves the same process of diagnosing the students' problem, administering treatment and measuring outcomes.

Once ATS has applied its training instruction techniques to many students, a history of training efficiency for the ATS will be available. This time outcome measures are not indicating student pilot performance, but establish the quality of training offered by the ATS instruction. In the same way that outcome measures offer comments on the effectiveness of training sessions in preparing the student, these ATS outcomes indicate the relative effectiveness of the training curriculum implemented by the ATS.

As changes to the instructional curriculum employed by the ATS are made, relative outcomes measures provide evidence regarding the efficacy of the change. In this way, the ATS employs the same mechanisms for evaluating training recommendations and training curriculums. Since training curriculums will take the form of a knowledge-based system, the ATS will have the ability to measure the effects of modifying its own reasoning processes.

ATS Components

The Easy Reasoner, CBReete++, and CPR products are proposed for the development of the ATS system. These products not only offer the knowledge representations needed by ATS, but the components are integrated with several object-oriented programming API's. Additionally, the products are supported by a company headed by Paul Haley, one of the leaders in Artificial Intelligence since the late 70's. Product support and specialized consulting is available from the experienced members of The Haley Enterprise.

Visual C++ on Windows 2000/NT is proposed as the development platform and will be used to integrate reasoning components. It will also be used to develop a Knowledge Base (KB) Editor. The KB Editor tool provides support for Conceptual Graphs (CG) to facilitate knowledge acquisition and analysis. Visual representations for the graphs will be manipulated by the KB editor and translated to the Knowledge Interchange Format (KIF) for use in ATS. Conversely, the KB editor will read from and permit the browsing of ATS knowledge structures.

Database repositories will be maintained in a relational database. The CBReete++ components utilize standard SQL access, so a standard Access database will be employed initially. As run-time issues appear, alternative large-scale databases will be considered to replace Access. In addition, the CG editor will provide the ability to output CG graphs in a node network form to an Excel spreadsheet. This format will allow KNOT to be used to analyze the relations found in both the case-base and the concepts used to classify cases. Figure 11 presents a schematic of the ATS component architecture.

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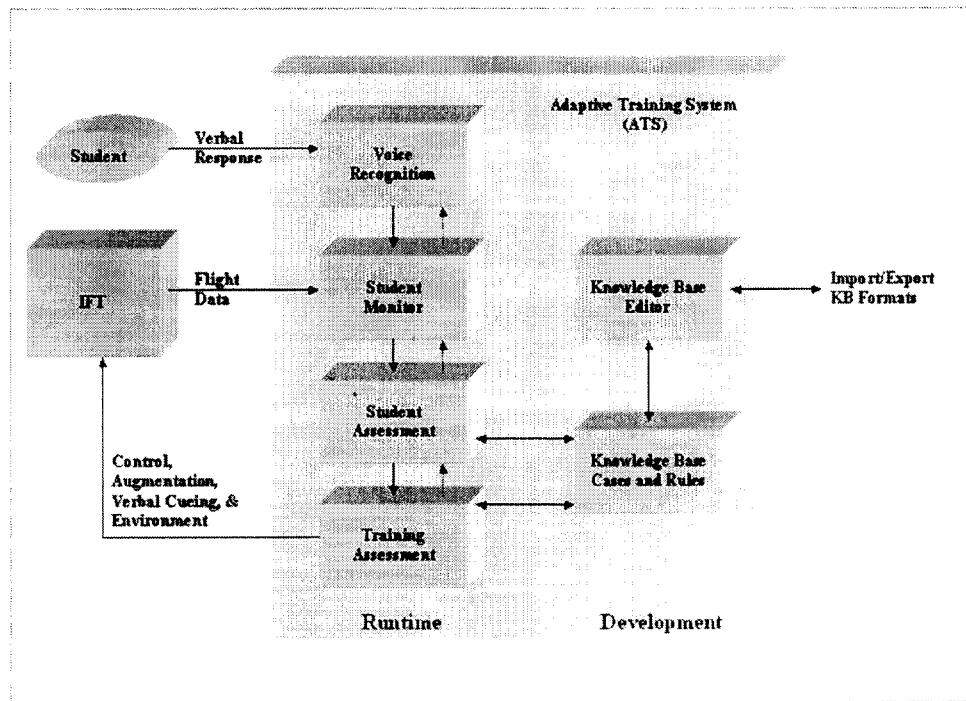


Figure 11. ATS Component Architecture

Voice Recognition

The primary purpose for the voice recognition component is to provide ATS with a means of confirming the student's understanding. As task understanding is called into question, ATS can ask questions using verbal cueing and obtain responses directly from the student. Task understanding can be called into question during either flight or classroom training sessions. The ATS, like an instructor, will have the potential of confirming a task understanding deficiency and provide the needed information without interrupting the current flight task.

The Voice Recognition module will be implemented in C++ using DragonDictate and Dragon Xtools. DragonDictate provides complete speaker independent voice control of the entire Windows environment. Dragon Xtools provides a C++ API to provide control, configuration, and monitoring of voice recognition activities in DragonDictate. The Student Monitor component of ATS will use Xtools to limit the expected responses in order to increase recognition accuracy.

Student Monitor

This component is responsible for obtaining all required student data. The primary source of data obtained from the student comes from the IFT. The Student Monitor (SM) component provides an Application Programming Interface (API) that will be used by IFT to send the data. The SM API will be implemented using TCP/IP sockets over a standard network connection to the IFT.

The SM will be implemented in C++ and provide data preparation for attributes used to describe student cases. It is anticipated that collections of various data post processing functions will be implemented to support data reduction from raw sources. For example, a Fast Fourier Transform (FFT) function will provide spectral analysis of the cyclic control input in order to support recognizing when the student is "over controlling".

The same types of data and analysis will be provided for establishing attributes of the helicopter as well. This will permit the Flight Handling Qualities of the helicopter flight model in IFT to be characterized along with the student. In some simulators, poor control of the vehicle in certain conditions can be the fault of the flight model and not the student. This analysis potential not only allows ATS to attribute the failure to the appropriate component (student or flight model), but also it can identify areas where negative transfer of training may be an issue as the student moves on to real vehicles.

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Configuration and control of the SM will be provided by the Student Assessment component, including starting and stopping the SM process. Depending on the type of training task being assessed, different types of post processing of student data may be required. The SM will receive instructions on what type of data is required and provide that data to the Student Assessment component using The Intelligent Memory module of CBReete++.

Student Assessment

The primary goal of this component is to provide a continuous assessment of a student's performance. It dynamically configures the Student Monitor component to provide requested student metrics and then employs concept recognition knowledge bases to establish the student's skill state and task understanding. The Student Assessment (SA) component, like the SM component, is configured specifically for the conduct of a particular training session.

For example, consider the "Maintain Lateral Position" task described in Table 1. The acceptable performance limits for this task may be driven several factors: wind velocity and variation, standard qualification standards, task duration, other required tasks, and the student's past performance. If there are no other required tasks, then the SA does not have to be concerned with the longitudinal vehicle position or forward and back cyclic control movements. In addition, collective and pedal controls inputs are not of concern to SA in this case. SA selects only those concepts relevant to the task(s) at hand for monitoring and evaluation.

The SA will be implemented in C++ using the CBReete++ and CPR components. The CBReete++ components will be used to establish the student's training progress as the current problem case. The CPR components will be used to decide on relevant concepts and metrics for the given task(s). As you recall, the CPR components provide an environment for employing case-based reasoning together with classical diagnostic production rules.

Representing knowledge that determines relevant concepts in the context of multiple tasks and varied student experience is complex. The SA will manage this complexity by representing specific relations between tasks, concepts, metrics, and historic performance independently using rules and cases. Tasks, or combinations of tasks, will imply relevant concepts. Relevant concepts and task specific historic performance implies acceptance criteria and metrics. The rule bases employed by SA will implement instructor expertise with regard to assessing a student in the context of required tasks and experience.

The SA configuration information establishing the student under test and required tasks is provided by the Training Assessment component. The Intelligent Memory (TIM) component of the CBReete++ component facilitates the sharing of context information. In addition, the Training Assessment component is responsible for the starting and stopping of the SA process.

Training Assessment

The Training Assessment (TA) component is the main control point for the ATS Runtime environment. ATS users interact with the TA Graphical User Interface (GUI) in order to control and monitor the complete training environment, including the IFT. The TA-GUI begins by establishing the student identification and setting default training goals.

The primary goal of the TA component is to represent expert instructor knowledge with regard to adapting a training curriculum to a specific student. The TA represents knowledge needed to decide what the next training task should be in the context of a particular student's case history. For new students that the system has no history of, some form of standard training curriculum might be employed for the specific training goal selected. For students that have interacted with the system before, the tasks would be customized so as to optimize training efficiency for that student.

The TA also has responsibility for controlling several aspects of the IFT. Flow control involves the starting and stopping of the IFT. Remote flight control involves the pausing (and continuing) of the flight model in addition to managing any flight control augmentation. Remote voice control passes phrases that the TA needs spoken to the student through the IFT. Remote environmental control manages values like wind direction and speed used by the IFT flight model and visibility used by the IFT image generators.

In order to support the required interfaces to the IFT, the TA provides an API that will be used in creating the ATS IFT. Figure 12 presents a schematic of the ATS IFT and its relationship to the ATS. Both the TA and SM API's will be employed to construct a fully encapsulated version of the IFT for use by ATS. Once started, the ATS IFT process connects to the TA through the TA API. Further connections to the SM are made as required based on requested tasks.

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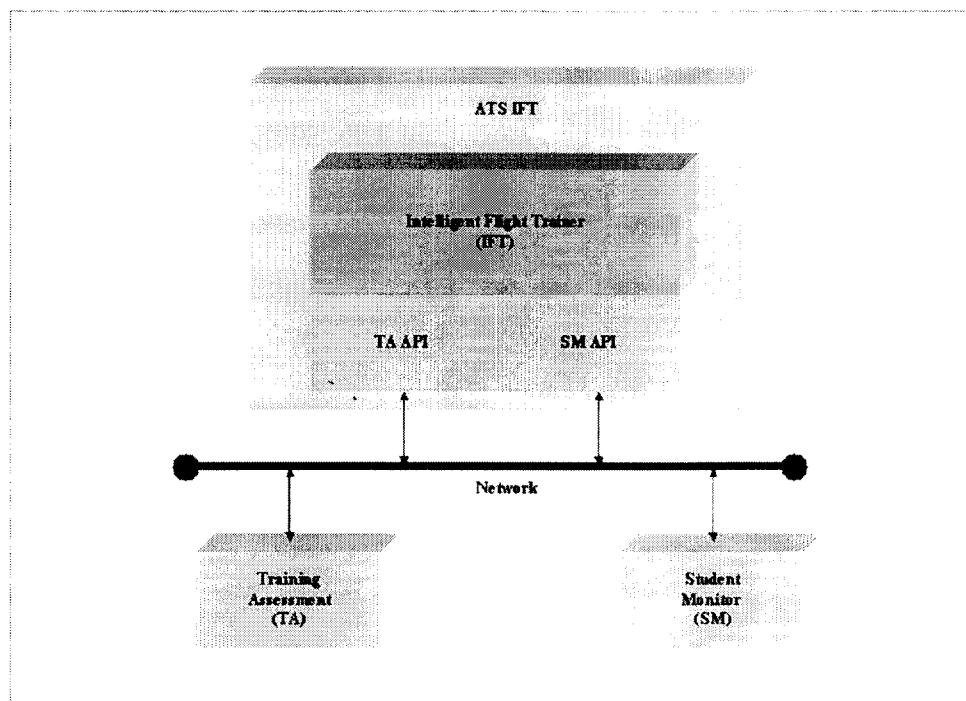


Figure 12: Encapsulating IFT for integration with ATS

The TA will be implemented in C++ using the CBRete++ and CPR components. The CBRete++ components will be used to establish the student's training program using previous training cases and induced decision trees. It will also be used to establish the current instruction parameters as an instruction case in support of post-instruction evaluation of the ATS instruction methods. The CPR components will be used to decide on relevant training tasks given the student's performance.

Initially, a student's history is consulted to establish the required tasks for the selected training goal(s). The tasks are sent to the Student Assessment (SA) module for use in configuring metrics and subsequently establishing the attributes required for monitoring by the SM. The knowledge employed by the TA in determining the training tasks is a combination of case based reasoning and diagnosis, as in the SA component.

For example, a new student may be given an initial task of lifting the helicopter to a 5-foot hover and maintaining lateral and horizontal position within 5 feet in a no wind condition. In this case all controls are active and not augmented. If the student performs this task within specified criteria, then the system moves on to the next task in the curriculum. If the student cannot respond within the specified criteria, the SA indicates the types of errors using the student assessment attributes. If the student initially lost control by over-controlling the lateral cyclic input, then the case base and/or diagnostic/treatment knowledge bases may suggest reducing the number of controls to lateral only and provide some minor control augmentation.

The process of determining whether Case-Based Reasoning (CBR) or classical diagnostic rule based processing is used to represent specific instructional knowledge is the focus of knowledge acquisition and engineering activities. In the beginning of system development when a case base does not exist, interviews with instructors will focus on identifying the taxonomy of student training progression and errors. This knowledge might be represented initially in the form of a classical diagnostic production system. As students are encountered, the case base grows and the performance of the current instructional knowledge base established.

During offline analysis of the student case base and the instructional knowledge base, a decision tree is induced from the case base. The differences between this decision tree and the existing diagnostic rule base are carefully analyzed to identify potentially missing concepts in the rule base. If differences exist but cannot be readily identified at this time, the case could be added to the case base and solution responses indicated by an expert. In the future similar cases will be adapted to this solution.

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If cases are simply remembered, you might wonder why it would ever be desirable to do the work of "re-representing" the knowledge in the case base using a diagnostic rule base. The issue is one of understanding and explanation. A Case-Based Reasoning system doesn't really know why it is making a decision. The system simply correlates cases and adapts previously determined solutions. The process of migrating concepts discovered in the case base to diagnostic rule bases is the primary mechanism for producing explanations of the ATS training curricula. The Knowledge Base Editor provides the analysis and modification of knowledge bases employed by the SA and TA components.

Knowledge Base Editor

This component is the main control point for the ATS Development environment. The KB Editor (KBE) provides for human access to all stored case base and rule base information manipulated by SA and TA. The primary aspects of knowledge base management supported by the KBE are the following:

1. Concept analysis of the student case base and induced decision trees,
2. Identification of student cases for use in decision making,
3. Concept analysis of the instructor case base and induced decision trees,
4. Identification of instructor cases for use in decision making,
5. Editing and management of all diagnostic rule bases,
6. Presentation of knowledge in the form of Conceptual Graphs,
7. Import and Export of knowledge in KIF and CGIF.
8. Export of appropriate knowledge in spreadsheet form.

Aspects 1 and 2 are identical to 3 and 4 except that they deal with the student and instructor, respectively. The student case base is analyzed to characterize the types and/or progression of errors that students make during training. The instructor case base is analyzed to characterize the types and/or progression of instruction techniques that succeed in achieving training goals.

Aspects 5 and 6 provide typical rule editing and rule base management functions. The graphical presentation of rule networks, case specific execution traces, and other knowledge base debugging functions are incrementally developed as needed. The display of rules and rule networks in the form of conceptual graphs should aid in the need for the real-time review of existing knowledge bases during knowledge acquisition interviews.

Aspect 7 and 8 provide for the interoperability of knowledge structures in other tools. Network analysis using KNOT is supported with the spreadsheet export. Other information analysis tools that accept KIF or CGIF can be used in the generation or analysis of ATS knowledge. CBREte++ will maintain the knowledge base in a relational database. Initially, an inexpensive database will be used until it becomes a bottleneck. Depending on the efficiencies of the access mechanisms and underlying hardware, other databases may be substituted later in the program.

System Production and Maintenance

ATS is a complicated knowledge based system. The successful development of ATS requires the employment of several tools to help manage the complexity of the development project itself. The CommonKADS methodology is proposed to organize the construction of the components within ATS. RationalRose, an object-oriented modeling tool, is proposed to represent the models required by the CommonKADS methodology. All aspects of the ATS project will be modeled to account for all activities and provide explicit representations for dependencies between components and requirements.

Microsoft Project 2000 is proposed to manage the schedule of development activities during the ATS development cycle. Many students and instructors will be needed for knowledge acquisition and system testing. Cognitive psychologists and knowledge engineers must collaborate on conceptual discovery and case-based analysis activities. It is anticipated that a major key to the success of bringing the program in on time and budget will be careful management of the limited personnel resources.

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Conclusions

While the goals of the ATS program are ambitious, the technical risks associated with the ATS development program are minimal. A mature, integrated, and supported product technology is available from a leading Artificial Intelligence (AI) tool vendor. The ability to represent knowledge structures in multiple forms, for use in several decision-making paradigms, supports incremental refinement. This incremental refinement capability encourages the use of ATS during its own development process.

Finally, while the design described tailored to helicopter hover training using the IFT, the structural elements and philosophy should support adaptive training in many student/instructor applications.

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